Typology of representative building designs within townships for energy efficiency in the City of Cape Town

by

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Declaration

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Abstract

African urbanisation currently embodies spaces that represent every scale of urban development. In the case of the City of Cape Town Municipality (CCT) in South Africa, the built environment is responsible for almost 40% of the total primary energy use. However, the preliminary investigation uncovered that there is currently limited understanding of the energy profiles of the various types of low cost buildings found within townships in South Africa, and that successful implementation of plans for sustainable energy provision within this sector is uncommon. In order to understand CCT's inclusive urban metabolism, the study sets out to fill this gap in knowledge and data regarding the current urban energy systems in the low cost building sector. The primary research aim of the study was to build a typology of low cost buildings, with regards to their energy profiles. As it is necessary to address the energy challenges holistically, the complexity and interconnectedness of socio-economic, environmental and energy systems were considered.

In order to achieve this, the following methods were employed: literature review; typology building; energy and thermal comfort modelling; and semi-structured interviews. The literature review followed themes of urbanisation; urban metabolism; sustainability in the built environment; low-cost buildings in Africa; and the energy landscape in South Africa, especially with regards to township architecture. To develop the building energy typology, 46 suburbs were identified as townships in the City of Cape Town, of which two representative ones were studied, namely Gugulethu and Manenberg. The buildings within these townships were classified into nine representative types: rowhouses; maisonettes; cottages; courts; government reconstruction and development programme (RDP) houses; single storey migrant labour hostels; two storey migrant labour hostels, and buildings known colloquially as '2-storeys'. Based on the building properties for each of the nine representative building types, energy consumption was modelled using DesignBuilder software. According to the four energy use consumption sources (heating; cooling; lighting and domestic hot water), the buildings were grouped relatively into three levels of consumption typologies: low, medium and high. Cottages and the two-storey migrant labour hostels formed the low consumption typology; maisonettes, single storey migrant labour hostels and '2-storeys' formed the medium consumption typology; and rowhouses, courts and RDP houses formed the high consumption typology. Results of the energy profile simulations revealed that the main

reasons for high energy consumption within township buildings was due to the often poor orientation of buildings on site; high occupancy rates; uninsulated walls and roofs; lack of ceilings; air leakage due to a lack of (properly) fitted window and door frames; the use of kettles as a primary source of water heating; and inefficient incandescent lighting.

Thermal gains graphs, also generated from DesignBuilder, revealed that most of the building types were thermally inefficient, i.e. they are hot in summer, and cold in winter due to lack of airtightness; overheating from a lack of shading elements; poor insulating capacity of structural components; and/or high occupancy loads. To enable future energy efficient design interventions in townships, the findings suggest that public and private entities need to become more transparent regarding the types of data available, and develop the existing data in order to encourage research-backed policies and projects which could lead to an alternative model of (township) construction. Retrofitting projects should incorporate ceilings in their design; provide wall insulation; plaster walls; use lightweight materials where possible; allow for customisation and expansion from original design; offer appropriate roof materials and shading elements; conduct airtightness tests; consider cultural positions on built structure; offer solar water heaters and rooftop PV; and replace incandescent light bulbs with energy efficient lighting. New buildings should also consider the orientation of the building on site.

Future work involves alleviating data scarcity challenges in this sector by making new data publicly available; quantifying the considerable amount of informal energy use within townships; and finding a means of consolidating different forms of energy profiling into a singularly measurable output. In order to meet the aim of understanding the city’s inclusive urban metabolism, it is vital that this data is combined with data on formal and existing energy flows, and modelled alongside the other relevant resource flows within the city.

Opsomming

Soos verstedeliking in Afrika tans daar uitsien, is daar ruimtes wat stedelike ontwikkeling op elke moontlike skaal verteenwoordig. In die geval van die Stad Kaapstad Munisipaliteit (SKM) in Suid-Afrika verteenwoordig die geboude omgewing ongeveer 40% van die totale primêre energieverbruik. Die voorlopige ondersoek het egter aangedui dat daar onvoldoende insig in die energieprofiele van die onderskeie soorte laekostegeboue in die townships van Suid-Afrika is, en dat planne vir volhoubare energievoorsiening in hierdie sektor selde suksesvol geïmplementeer word. Ten einde ’n duideliker begrip van die SKM se inklusiewe stedelike metabolisme te kan bekom, pak hierdie studie die kennis- en datagaping ten opsigte van die bestaande stedelike energiestelsels van die laekostebousektor aan. Die primêre navorsingsoogmerk met die studie is om ’n tipologie van laekostegeboue met die oog op hulle energieprofiele saam te stel. Omdat hierdie energieuitdagings holisties aangepak moet word, is die kompleksiteit en die onderlinge verbondenheid van sosio-ekonomiese, omgewings- en energiestelsels in ag geneem.

Die metodes wat gebruik word om hierdie oogmerk te bereik, behels onder meer ’n literatuuroorsig; tipologiesamestelling; energie- en termiesegerief-modellering; en semi-gestruktureerde onderhoude. Temas wat in die literatuuroorsig ondersoek is, sluit in verstedeliking; stedelike metabolisme; volhoubaarheid in die geboude omgewing; laekostegeboue in Afrika; asook die energielandskap in Suid-Afrika, veral wat die township-argitektuur betref. Vir die samestelling van die gebou-energietipologie is 46 woongebiede as townships van die Stad Kaapstad geïdentifiseer, en twee verteenwoordigende gebiede, te wete Gugulethu en Manenberg, is in die studie gebruik. Die geboue in hierdie townships is in nege verteenwoordigende tipes verdeel, te wete: skakelhuise; skakelwoonstelle; kothuise; howe; die staat se heropbou-en-ontwikkelingsprogramhuise (HOP-huise); enkelverdiepinghostelle vir trekarbeiders; dubbelverdiepinghostelle vir trekarbeiders; en geboue wat in die volksmond ’2-verdiepings’ genoem word. Energieverbruik is met behulp van DesignBuilder-sagteware gemodelleer na aanleiding van die geboukenmerke van elk van die nege verteenwoordigende geboutipes. Met die vier energieverbruiksbronne (verhitting; verkoeling; verligting en huishoudelike warm water) in ag genome, is die geboue tipologies volgens drie verbruiksvlakke geklassifiseer: laag, medium en hoog. Kothuise en tweeverdiepinghostelle vir trekarbeiders verteenwoordig die laeverbruiktipologie;

skakelwoonstelle, enkelverdiepinghostelle vir trekarbeider en ’2-verdiepings’ vorm die mediumverbruikstipologie; en skakelhuise, howe; en HOP-huise maak die hoëverbruiktipologie uit. Volgens die resultate van die energieprofielnabootsings is die hoofredes vir energieverbruik in township-geboue grootliks te wyte aan die swak oriëntasie van die geboue op die perseel; hoë okkupasiekoerse; ongeïsoleerde mure en dakke; gebrek aan plafonne; ontsnapping van lug vanweë ’n gebrek aan (behoorlik) geïnstalleerde venster- en deurrame; die gebruik van ketels as primêre waterverhittingsbron; en ondoeltreffende gloeilampverligting.

Termiesetoename-grafieke wat ook met DesignBuilder geskep is, dui daarop dat die meeste geboutipes termies ontoereikend is, dit beteken die geboue is warm in die somer en koud in die winter vanweë onvoldoende lugdigtheid; oorverhitting by gebrek aan beskaduwingselemente; swak isoleerkapasiteit van strukturele komponente; en/of hoë okkupasieladings. Die bevindings dui op bepaalde voorvereistes betreffende toekomstige ontwerpintervensies om informele nedersettings energiedoeltreffend te maak, naamlik samewerking tussen openbare en privaat entiteite en die ontwikkeling van die bestaande data met die oog op navorsingsgesteunde beleide en projekte om ’n alternatiewe model van township-ontwikkeling aan te moedig. Herbouprojekte behoort plafonne in die ontwerp in te sluit; muurisolering te voorsien; muurpleistering te doen; liggewigmateriaal te gebruik waar moontlik; die oorspronklike ontwerp aan te pas en uit te brei; gepaste dakmateriaal en beskaduwingselemente aan te bied; lugdigtheidstoetse uit te voer; kulturele posisies oor geboude strukture te oorweeg; sonwaterverhitters en fotovoltaïese dakstrukture aan te bied; en gloeilampe met energiedoeltreffende verligting te vervang. By nuwe geboue moet die oriëntasie van die gebou op die perseel in ag geneem word.

Werk vir die toekoms behels om die uitdagings van die dataskaarste in hierdie sektor aan te pak aan die hand van nuwe data wat van owerheidsweë bekom word; die aansienlike hoeveelheid informele energieverbruik in townships te kwantifiseer; en te bepaal hoe verskillende vorme van energieprofilering in ’n unieke meetbare uitset gekombineer kan word. In orde om die stad se inklusiewe metabolisme te verstaan is dit krities dat hierdie data saamgevoeg word met bestaande en formele data op energiestrome, en langsaan ander relevante hulpbronbewegings in die stad verstaan word.

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List of Acronyms and Abbreviations

BNG	Breaking New Ground
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CBD	Central Business District
CIB	Conseil International du Bâtiment, or International Council for Research and Innovation in Building and Construction
CFL	Compact Fluorescent Lamp
CRSES	Centre for Renewable and Sustainable Energy Studies
DoE	Department of Energy
DHS	Department of Human Settlements
EE	Energy Efficiency
EEDSM	Energy Efficiency Demand Side Management
EIA	Energy Intelligence Agency
FBAE	Free Basic Alternative Energy
FBE	Free Basic Electricity
GBC	Green Building Council
GBCSA	Green Building Council of South Africa
GCRO	Gauteng City-Region Observatory
GHG	Greenhouse Gas
GWh	GigaWatt-hours
HDA	Housing Development Agency
IUCN	International Union for Conservation of Nature
KWh	KiloWatt-hours
LEED	Leadership in Energy and Environmental Design
MCPF	Manenberg Community Policing Forum
MDGs	Millennium Development Goals
MIT	Massachusetts Institute of Technology
MoE	Margin of Error
NEES	National Energy Efficiency Strategy

NDP	National Development Plan
NRF	National Research Foundation
RDP	Reconstruction and Development Programme
SDGs	Sustainable Development Goals
SBTool	Sustainable Building Tool
SU	Stellenbosch University
TABULA	Typology Approach for Building Stock Energy
TRA	Temporary Relocation Area
UM	Urban Metabolism
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WCED	World Commission of Environment and Development

Glossary

Energy efficiency

'Energy efficiency' refers to the reduction in energy consumption by use of energy-efficient technologies or change in energy-use behaviours. An energy-efficient technology is one that produces the same service or output with less energy input, and efficient behaviour refers to consciously choosing such technologies or similar methods in order to reduce energy consumption.

Global North and Global South

For the purpose of this study, the United Nations' distinction will be used: countries of the Global North include those in Europe; United States of America; Canada; Australia; New Zealand; as well as Hong Kong; Japan; Singapore; Taiwan and South Korea; while countries of the Global South include all the remaining countries, including South Africa.

First ring

This area refers to a radius of 20 km around the City of Cape Town's central business district.

Informal settlement

The Department of Human Settlements (2009a: 16) and the Housing Development Agency (2013: 53) identify settlements as informal if they are located on land which is not officially sanctioned or documented, where there is restricted public and private sector investment, especially limited in terms of municipal service delivery, the population is poor and vulnerable and/or susceptible to social stress.

Legal ('formal') buildings

For the purpose of this study, 'legal buildings' refer to those that are built according to approved plans, and acknowledged by the City of Cape Town municipality. These do not include shack dwellings, or backyard shacks. Examples of relevant buildings would be Reconstruction and Development Programme (RDP) or government subsidised dwellings; privately-built dwellings and community buildings; subsidised hostels. A distinction is made between private and government-subsidised buildings.

Low-cost buildings

For the purpose of this study, all legal buildings found within townships and informal settlements are considered to be low-cost.

Migration

For the purpose of this study, migration refers to *internal* migration. The term refers to the movement of people from one province or area in a country, to another province or area within the same country. An example of this is the internal migration of people from the Eastern Cape to the Western Cape.

Sustainable development

Sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987).

Township

The International Encyclopaedia of Social Sciences describes townships as “land formally allocated to hosting the site of a town” (Bond 2008: 405). The City of Cape Town does not explicitly distinguish between the terms ‘township’ and ‘suburb’. For the purpose of this study, however, townships will be regarded as residential suburbs where more than half of the households earn an income of less than R3200 per month, and are previously disadvantaged in terms of their racial profile.

Typology

‘Typology’ refers to a taxonomic classification according to specified characteristics. For the purpose of this study, the typologies are generated according to the building types within the selected representative townships, based on their physical characteristics, and related to energy consumption profiles.

Urban metabolism

Currie (2015), defines urban metabolism as the “complexity of socio-technical and socio-ecological processes by which flows of materials, energy, people and information shape the city, service the needs of its populace, and impact the surrounding hinterland”. In his definition, he refers to this metabolism as an emergent property of the city. As such, it becomes a tangible aspect which can then be measured, analysed and changed. Due to its complex nature, changes to any city process will affect the entire urban metabolism, shaping how a city grows, produces energy, and eliminates waste (Kennedy et al. 2007).

1 Introduction

1.1 Background

With the global discourse on sustainable development gaining prominence more than a decade ago, the poverty-environment conundrum became a major concern and was keenly debated (Kaika & Swyngedouw 2011; Satterthwaite 2003; WCED 1987; Birkeland 2008). Policy makers have, for the most part, taken two separate positions: those concerned with the plight of the poor; and those who believe that they are fighting for the survival of our planet. Despite the extensive attention paid to the sustainability agenda, not much has been achieved with respect to altering socio-ecological conditions, and in activating a collective initiative towards a sustainable future in cities of both the global North and South (Kaika & Swyngedouw 2011).

The world's population is predicted to reach 9 billion by 2050, 60% of which will live in cities (Robinson et al. 2012). In 2014, South Africa's population was estimated at 54 million, with the average population growth rate at 1.58% per annum (Statistics South Africa 2014b). The proportion of the population living in urban areas in South Africa in 2011 was 63% (Robinson et al. 2012; World Bank 2014). One of the primary contributing factors towards urbanisation in South African cities is migration from other provinces, presumably for economic reasons. Economic migrants seek improved access to services and generally, a better life (HDA 2013: 8; Peberdy 2013). Gauteng, for example, is the most populous province in the country, and the fastest growing in terms of both population and economy, even though it is the smallest geographically-speaking. It is aptly referred to as the province of migrants, with 44% of the population having been born elsewhere.

Gauteng and the Western Cape are the most popular receivers of migrants in South Africa (Human Sciences Research Council 2005). However, while Gauteng maintains a higher net gain in migration across the provinces, it experiences a net loss of migrants to the Western Cape (Human Sciences Research Council 2005). In the Western Cape, the current ratio of in-migrants to out-migrants, is 2:1, of which half are from the Eastern Cape (HDA 2013: 8; Britz 2002). According to Britz (2002), the reason from this migration is predominantly because of a lack of local employment in the Eastern Cape, the third most populous, and one of the poorest provinces in the country (HSRC 2014; Statistics South Africa 2014b). As a former homeland of the Apartheid era, this province is, comparatively, one of the worst in terms of service delivery, infrastructure and employment within South Africa (Britz 2002). The Western Cape, in contrast, and specifically the City of Cape Town municipality, offers far more in terms of social indicators, economic prospects, housing and health infrastructure (Britz 2002).

However, not all migrants prosper in their urban promised lands. In cities like Cape Town, migrants often find themselves as part of the growing population of what might be referred to as the urban poor. The urban poor often populate what is known as the 'urban periphery' – the area just outside of the city's official boundaries, expanding these borders and contributing to urban sprawl. While not all peripheries are, by definition, *poor*, this is the case for most within the South African context. Townships and informal settlements are formed in these areas, where delivery of basic services (sanitation, water, access to electricity, safety) is limited, and environmentally non-beneficial mixed land use persists. These areas remain highly segregated socially, economically, and spatially (UNDESA 2011: 125) compared to areas within the regulated zones of the city. The townships are also generally far away from the wealthy inner city, and often neglected by the government (Department of Human Settlements 2009; Weakley 2013). Furthermore, the increase in the population of this urban periphery, where the majority of migrants find themselves (UNDESA 2011), implies an increased demand for housing requirements and service delivery, including among others, the provision of energy.

The related growing energy demand (U.S. Energy Information Administration 2014), and emerging polycrisis (Swilling & Annecke 2012) regarding energy security and environmental effects, requires decision makers to establish comprehensive plans for urban areas. Often, the dire need of those within the low-cost housing settlements is neglected. This neglect is often ascribed to a lack of capacity, and a refusal to take responsibility by the administration (Huchzermeyer 2004). Despite new acknowledgement in national policies that these settlements are, in fact, a long-term feature of the South African urban landscape (Gaunt et al. 2012), action needs to be taken in designing measures for sustainable energy consumption within these spaces.

The growing energy demand within these areas is still being met by improving and expanding energy production almost exclusively from fossil resources, as well as by managing energy efficiency from demand side (Sebitosi 2010; Tsikata & Sebitosi 2010). However, these solutions have physical limits. Developing policies that are both scientifically and publicly acceptable are often fraught with difficulty (Brent 2014), therefore progress is slow. As the complexity and interconnectedness of socio-economic, environmental and energy systems within these contexts become steadily more apparent, there is increasing pressure on governments, policy makers, and managers to take a holistic approach to the energy challenges that are faced by various dwelling types of the low-cost building sector.

To this researcher's knowledge, while similar studies have been executed, there has been limited investigation into building typologies exclusive to the Western Cape, which considers the energy profile of the buildings. There are numerous names by which these studies refer to building typologies. Some are called 'reference buildings', while others are referred to as 'benchmark models'. While they might employ the same definition, they vary in terms of either physical or other predetermined characteristics, as well as what they aim to examine. Typologies exist for cities across the world, but the majority of this work is focused on countries of the Global North. As such, the criteria established for building typologies was not necessarily replicable to African, and generally, Global South country contexts. For example, Attia et al. (2012), generated representative typologies of Egyptian residential building stock based on their average energy consumption, in order to evaluate the financial and energy benefits of the country's new energy standard. A similar study was undertaken by Filogamo et al. (2014) in the Sicilian region, and by Kragh and Wittchen (2014) in Denmark. Kragh and Wittchen's study (2014) was financed by Typology Approach for Building Stock Energy Assessment (TABULA), which resulted in numerous other projects within the European Union. While these studies are valuable and often overlap in terms of methodology, characteristics used to define their typologies cannot be imposed on the South African context. A study conducted closer to home by the Architecture Department of eThekwini municipality investigated the growing housing backlog and continually increasing rates of urbanisation in the area, which results in reinforced infrastructure limitations (eThekwini Municipality 2013). The primary objectives of this typological study was "to inform the optimisation of quality and sustainability in the design and ongoing delivery of subsidy housing" (eThekwini Municipality 2013). By doing this, the study aimed to propose housing typologies most suitable for application within informal settlement upgrades in their context. Storie (2012) generated a list of low income settlement types built on dolomitic ground for the Gauteng City-Region. South Africa is a diverse country with each region presenting its own challenges.

This study was also part of a wider project, 'African Cities Typology, an in-depth analysis for South African cities' resource consumption', funded by the National Research Foundation (NRF). The project aims at an understanding of South Africa's urban population growth and its implications for future resource consumption and requirements.

1.2 Problem Statement

The preliminary investigation suggests that typology studies for building designs exist both internationally and, to a lesser degree, nationally. There is currently limited understanding of the various types of low-cost buildings and their related energy flow patterns, as found within townships and other informal urban settlements within the City of Cape Town municipality, Furthermore, while plans do exist for integrating sustainable energy provision and consumption within the informal low-cost buildings, successful implementation thereof is highly uncommon. In order to understand the current informal urban energy situation, and the challenges of energy systems in low-cost building sectors of the City of Cape Town, this study investigates the energy profiles of the buildings within the townships of Gugulethu and Manenberg. It is envisioned that potential insights towards revised, context-specific strategies that would contribute positively towards a sustainable, energy efficient, and affordable built environment in the City of Cape Town municipality region will be determined through this investigation.

1.3 Research Objectives

The research aims primarily to build a typology of low-cost buildings, with regards to their energy profile. The objectives of this study are:

i. To classify representative low-cost building types in selected representative townships within the City of Cape Town
ii. To examine energy consumption of the representative low-cost building types in the selected representative townships

iii. To develop typologies of representative low-cost building types based on their energy profile in the selected representative townships
iv. To determine the limitations of conventional and alternative energy systems within the low-cost building sector in the City of Cape Town

1.4 Rationale for the Study

This study classifies buildings within the City of Cape Town's townships by their current energy use. After identifying the current challenges of conventional and alternative energy systems present within this sector, a model of the energy use of these representative buildings was developed. This was in order to identify feasible energy efficiency measures that stimulated the implementation thereof in these poorer communities.

My background in architecture led me to the focus of this research, and my work experience in energy modelling, green building design and consulting grounds the interest. During my first postgraduate year at the Sustainability Institute in Stellenbosch, I participated in a number of modules with recurring and overlapping themes. These themes engaged with informality, the data scarcity within townships and informal settlements, and the complexity of the greater socio-economic and political framework within which this *informality* lies entangled. It was vital to the study that these themes be revisited in order to tackle the reality of the current low-cost built environment, and its critical relevance to the urban metabolism of the city.

While there are similarities in approach and objectives, my study becomes distinct and important in that it aims to contribute to filling the gap in knowledge and data regarding the types of buildings and their related energy consumption within the townships and informal settlements around the City of Cape Town, in order to understand the city's inclusive urban metabolism.

1.5 Limitations of the study

The following limitations were recognised:

i. The study only focuses on low-cost buildings that were legally recognised by the City of Cape Town municipality.

ii. Migration, which contributes to increased urbanisation within the informal settlements, was limited to internal migration within provinces, and did not take into consideration international migrants' occupation of land.

iii. In modelling the energy use of the representative types of low-cost buildings, embodied energy was not considered.

1.6 Research Strategy

The research strategy involved several steps aimed at developing a clearer understanding of the research problem in order to achieve the associated objectives of the study (see Figure 1.1):

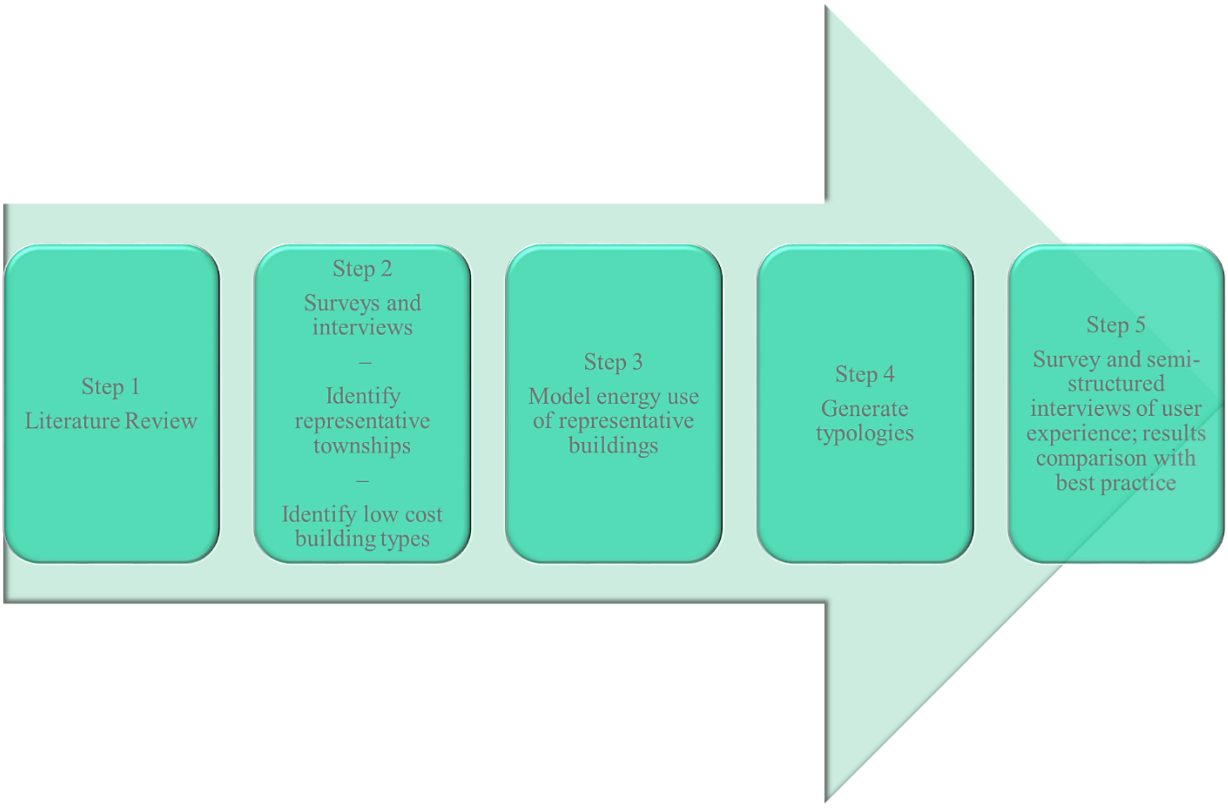


Figure 1.1 Strategy of research study

While the diagram is seemingly linear in progression, the research continuously evolves throughout the different phases, each informing and being informed by the others. The first step of the research strategy, along with the fifth, was important for achieving the third research objective, and involved reviewing the most recent and relevant academic and grey literature according to certain identified themes. These themes were urbanisation and urban metabolism; sustainability in the built environment; low-cost buildings; building typologies; and energy efficiency in architecture. Through the literature review, it became apparent that a bottom-up approach was needed in order to generate typologies of the low-cost building types within the townships of the City of Cape Town.

Step 2 was followed in order to meet the first research objective, namely classifying low-cost buildings into their relevant representative types within the City of Cape Town. Questionnaires were distributed and interviews conducted, in order to determine what kinds of energy systems existed in the sites. Appliance loads were noted, and it was determined how many electricity and energy sources were used on an average month in summer and in winter. By driving with a journalist who frequently works in the townships of Gugulethu and Manenberg, and knows the area very well, I was able to take photographs of buildings within the two sites, and to get to meet prominent members of the community. Thereafter, a template was created based on precedents which were discovered during the preliminary literature review, in order to complete step 3 and to meet objective two of this study.

In step 3, using the data gathered per building, energy models were generated in order to conceptualise the amount of energy used in the buildings. To verify this information, actual appliance loads were investigated, as well as electricity costs per month per type of building. The responses to the questionnaires circulated in step two were documented and analysed, in order to compare the energy patterns, both theoretical and practical, to the building's design and other predetermined factors. This was in order to meet the second objective of examining the energy consumption of the different building types.

In order to meet the third objective, step 4 was followed: the building types were categorised based on their four major energy loads making up their energy profile.

Step 5 involved *in situ* personal interviews with members of the community and people who worked within the community in a knowledgeable capacity. A review of the results from the models was compared to the building designs, to determine where the problems lie, and how these might be addressed using viable technologies and design measures.

1.7 Chapter Outline

Figure 1.2 explains the objectives of each chapter in relation to meeting the three research objectives of the study.

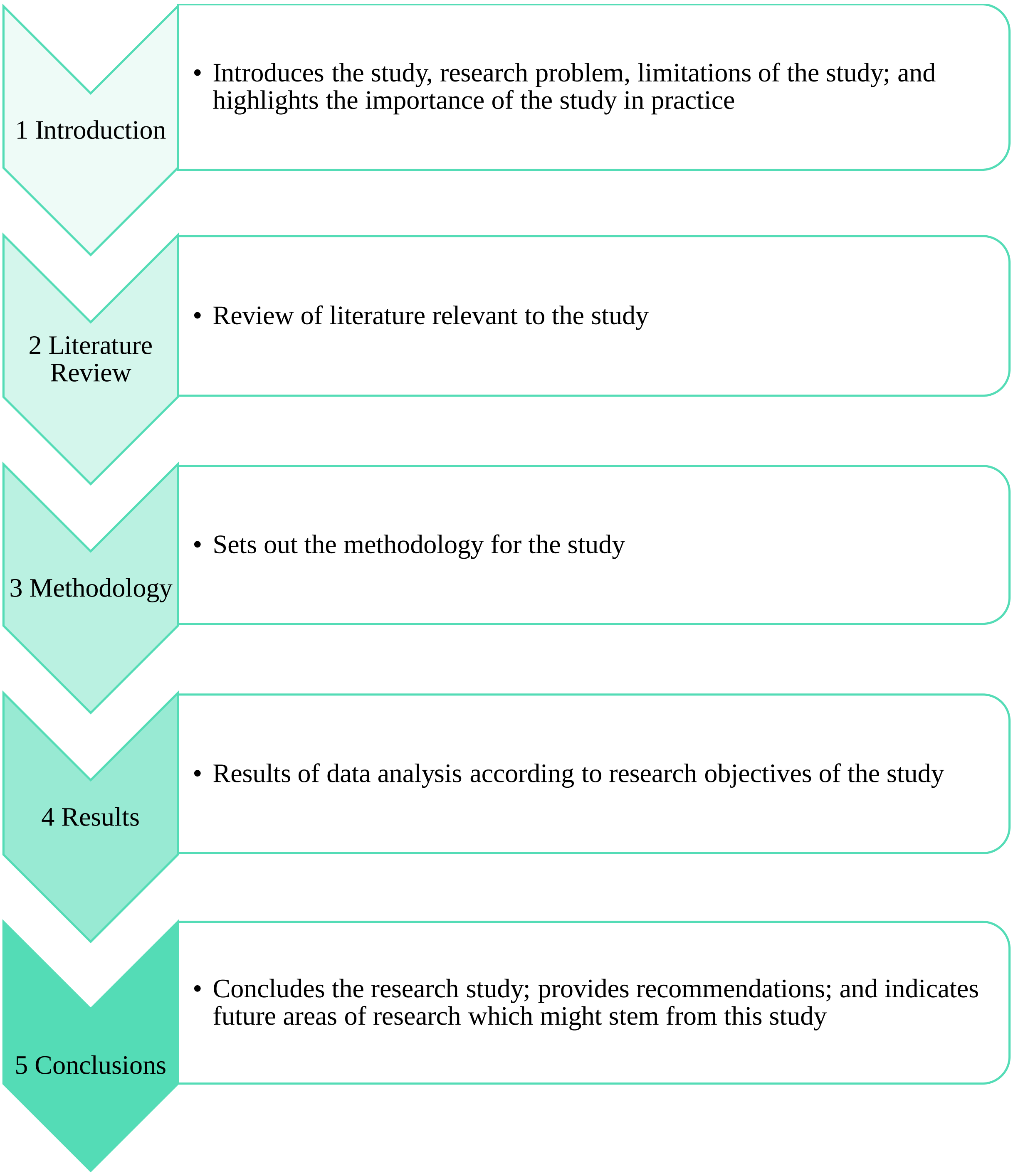


Figure 1.2 Chapter Outline

2 Literature Review

2.1 Introduction

In proportion to its population, the world is becoming increasingly urbanised (Satterthwaite 2003; Bojo & Reddy 2003; WCED 1987). According to Brown (2008), more than half of the world lives in cities; effectively making humans an urban species (Brown 2008: 192). This phenomenon of urbanisation is not exclusive to countries of the Global North – on the contrary, the developing world has been exponentially urbanising and will continue to do so (Bolnick 2010), especially for African and Asian cities , as can be seen in Figure 2.1. As such, there is a growing need for appropriate measures to be taken in order to ensure that the city becomes one which is sustainable in terms of its resource flows, the livelihood of its societies across socio-economic distinctions, and the natural landscape and environments which the city inevitably transforms during its growth (Satterthwaite 2003).

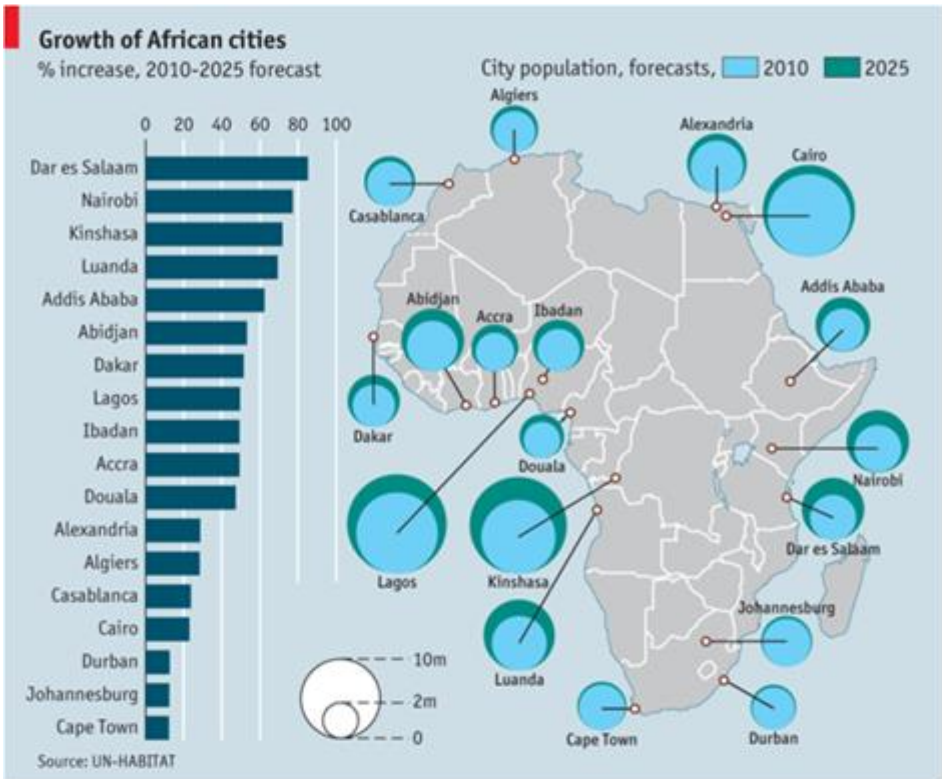


Figure 2.1 Growth of African cities

Source: The Economist Online (2010)

The sections following review the literature on key concepts in this thesis, as informed by the research objectives. The global issue of urbanisation and the driving concept of urban metabolism are discussed, in order to provide a base for the literature on sustainability within the built environment, which addresses objective four. Low-cost buildings are required to sustain the growing urban population. As such, a national and local context for this is investigated in order to meet research objective one. In order to meet research objective three of this study, literature on building typologies, both international and those in South Africa, is analysed. To contribute to data on energy as a resource flow within the City of Cape Town, information on energy conservation and efficiency measures within the country and City of Cape Town becomes important. For this purpose, policies were reviewed in order to determine appropriate approaches to establish energy efficiency within buildings in townships and informal settlements, in line with meeting research objective four.

2.2 Urbanisation

This section introduces the concept of urbanisation, a socio-ecological process, by outlining the origin and development of this concept. The drivers of urbanisation are discussed, as well as the ways in which it is manifested in the world, with specific focus on the manner in which urbanisation transformed cities in the African continent.

Urbanisation is defined as the process of human migration from rural areas to cities. The first wave of global urbanisation began in the 18th century. In a period of 200 years, between 1750 and 1950, the populations of Europe and North America increased by 2720% (Swilling & Annecke 2012). The period was defined by both romance and reason, respectively, with the beginnings of both the Classical Revival/Neoclassical era and the Modernist Movement shaping the built environment. Although it took a while for the world to embrace the minimalism of the Modernist movement, it became the dominant global movement by the end of the Second World War. Former distinctions between architects and engineers became vague because of the unification of form and function in this era (Marien & Fleming 2004). An aesthetic of the *city as a machine* was created in the hopes that industrialisation and *the machine* would liberate people from their reliance on nature, and there was optimism that machines would eventually lessen the need for hard labour, thereby securing social equality (Marien & Fleming 2004).

Le Corbusier, the architect widely recognised as the father of this movement, was responsible for numerous social housing schemes across the now-urban North, all inspired by the concept of houses being “machines for living, containers for families, and extensions of public services” (Marien & Fleming 2004: 594). His work was absolutely reductionist, and it inspired the design of cities and urban settlements all over the world (Swilling & Annecke 2012). The essence of modernism, namely “progress, rationality, secularity, universality” (Swilling & Annecke 2012: 111) became the template for city design.

The second wave of urbanisation began around 1950, and would take a third of the time to populate mostly developing countries with more than ten times as many people as in the first wave (Goven et al. 2012; Swilling & Annecke 2012). By 2050, an additional 3 billion people will be concentrated in Africa and Asia (Goven et al. 2012; Swilling & Annecke 2012). The following drivers are responsible for the second wave of urbanisation (Swilling & Annecke 2012; UNDESA 2011; Gospodini et al. 2008):

- Declining ability of homelands to support the natural growth of the people, which results in the populations migrating from rural areas to cities (the rural-urban migration);
- Natural growth of populations within cities through births and deaths; and
- Rising concentrations of political and economic changes brought about by technological innovations and globalisation, especially within developing countries.

According to Parnell and Pieterse (2014: 1), Africa is going through an ‘urban revolution’. In the next fifteen years, the growing population of cities will inevitably transform their landscapes as demand for resources, such as energy and construction materials, intensifies (Parnell & Pieterse 2014; Satterthwaite 2003). Batty (2008) states that, as these cities grow at different rates, the energy balance used to sustain them, also changes. Figure 2.1 shows this growth in population in scale, while Figure 2.2 demonstrates that, while both urban and rural areas expand, the rate at which cities develop is expected to be rapid. Goven et al (2012: 186) states that with urbanisation, African cities currently accommodate more than a billion inhabitants, a number which exceeds both the urban and rural populace of the West. To put the revolution in context, Parnell and Pieterse (2014) allege that African cities currently have a combined population greater than Europe, Australasia, North or South America; fifty of the largest cities in Africa accommodate a population of more than a million people each. While the urbanisation process has been delayed in Africa compared to the rest of the world, it has become quite a characteristic feature in African cities (Parnell & Pieterse 2014). African and Asian cities have the highest growth rates overall (Anderson et al. 2015), however, this second wave of urbanisation results in the expansion of existing cities, instead of the creation of new ones. Small, intermediate cities, also known as *secondary cities* (Goven et al. 2012; Swilling & Annecke 2012; Anderson et al. 2015) arise in lieu of large mega-cities. It is predicted that by 2030, the majority of city dwellers will call these cities, with less than 100 000 inhabitants, home (Goven et al. 2012).

To this end, it can be stated that Africa no longer exemplifies a continent of towns and villages, but in fact embodies spaces that represent every scale of urban development (Parnell & Pieterse 2014: 4). According to UN-Habitat, this is vital for achieving "sustained economic growth or rapid social development" (UN-Habitat 2010: 6). The State of the World's Cities report brings attention to the fact that no country has prospered economically without urbanising, although urbanisation also goes hand-in-hand with growing levels of "informality, illegality and unplanned settlements" (UN-Habitat 2010: 6). Regardless of this, cities have the potential to address poverty due to their economies of scale and proximity, which is conducive to high levels of productivity (UN-Habitat 2010).

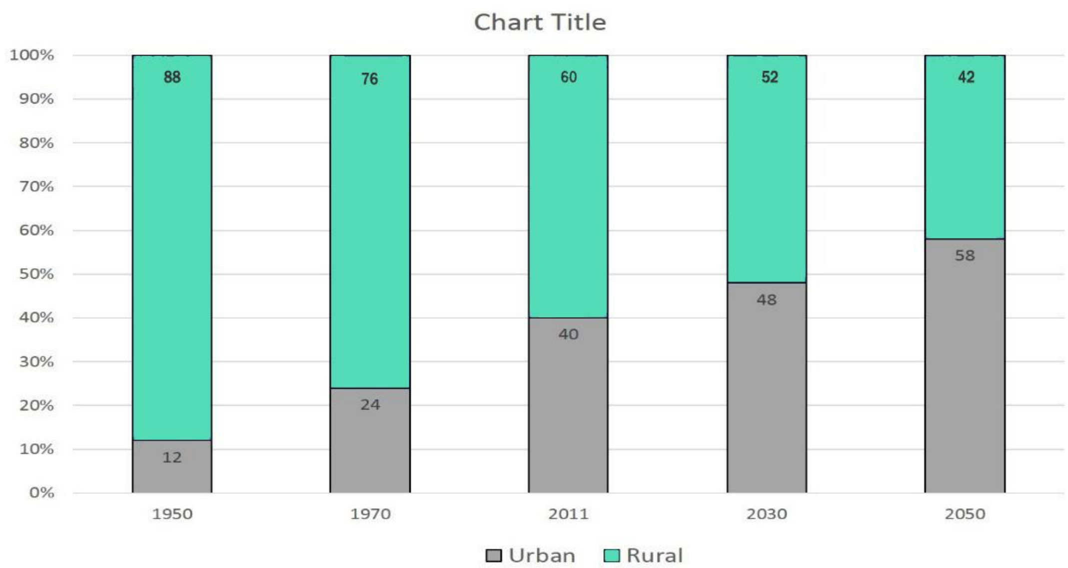


Figure 2.2 Africa's urban and rural population, in percentages, 1950-2050

Adapted from UNDESA (2011)

Cities are places that are made up of "dense networks of interwoven socio-spatial processes that are simultaneously human, material, natural, discursive, cultural, and organic" (1999, in Kaika & Swyngedouw 2000: 567). Kaika and Swyngedouw (2000) are of the opinion that there is no such thing as an unsustainable city; that there are only a series of urban and environmental processes that negatively affect some social groups, while benefiting others. This is recognised by Ferrao and Fernandez (2013) as *flows*, which include the influx and outflow of resources such as water, energy, and waste. A copious amount of metabolisms and flows support and maintain urbanity through combined environmental and social processes, and are infinitely interconnected (Kaika & Swyngedouw 2011). This collection of complex processes which shape the city is recognised as urban metabolism, which is explored further in section 2.3.

2.3 Urban metabolism

This section explores the study of urban metabolism, and the manner in which it relates to the contexts of sustainability and the built environment, especially with regards to energy. There are numerous definitions of and approaches to the analysis of urban metabolism. However, there is a lack of consensus on the term's epistemology, and how to uniquely relate it to the context of a city. Due to the concept's roots in fields of study outside the social sciences, it is debatable to what extent these origins can be referred to for clarity. However, its evolution through the decades can also be attributed to this transdisciplinary appeal (Golubiewski 2012; Lin et al. 2012).

2.3.1 Evolution of the concept

Karl Marx is credited with introducing the term 'metabolism' to the social sciences (Wachsmuth 2012; Zhang 2013). The term was used by Marx to refer to the mutually dependent relationship between society and nature, through the process of labour and the "capitalist system of commodity exchange" (Wachsmuth 2012: 507; Broto et al. 2012). In 1965, Abel Wolman became the first person to use the concept of metabolism in reference to a city. He recognised the issues of the deteriorating air and water qualities in American cities, and, in response, applied the biological concept of metabolism to a hypothetical city with a population of 1 million (Fischer-Kowalski 1998; Kennedy et al. 2007; Saldivar-Sali 2010). Wolman equated the metabolic requirements of the city to "materials and commodities needed to sustain the city's inhabitants at home, at work, and at play" (Wolman 1965: 179). This brought attention to the interrelated impacts of consumption and waste on a city.

In biology, 'metabolism' is defined as the biochemical reactions that are carried out by living cells in order to sustain life's many processes (Fischer-Kowalski 1998; Saldivar-Sali 2010;

Wachsmuth 2012). Organisms consume resources and excrete waste in order to function. It is essentially a process consisting neatly of inputs, throughputs, and outputs. Drawing on their similarities to organisms, cities can be said to “transform raw materials, fuel, and water into the built environment, human biomass and waste” (Decker et al. 2000: 715). Similarly, Holmes and Pincetl applied the biological concept of metabolism to cities in the transformation of “incoming raw materials, food, water, and fuel into physical structure, biomass and waste” (Holmes & Pincetl 2012: 2). They explained that cities are ultimately complex systems forged by social, economic and environmental factors.

However, many researchers have found this metaphor limiting because of its linearity, and the focus on a singular organism, as opposed to the complexity of relationships between a multitude of organisms and their environments, such as in the study of metabolism within ecology (Kennedy et al. 2011; Wachsmuth 2012; Currie 2015). As such, a more apt analogy was uncovered within the study of ecology, which likens the concept of a city to that of an ecosystem. Ecologists describe ‘metabolism’ as the sum total of all the processes between organisms within their environments/ecosystems. This definition has been applied in the commonly cited description from an urban ecology point of view, where urban metabolism is “the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and the elimination of waste” (Kennedy et al. 2007: 44). Naturally, ecosystems produce and maintain their own energy and processes, and are therefore an appropriate model on which to develop a sustainable city (Kennedy et al. 2011).

An architect, Kisho Kurokawa, argues that cities should be designed to evolve and be “flexible enough to maintain a constant cycle of growth, transformation, and death of its parts without the destruction of the whole” (Broto et al. 2012: 853). This recommendation embodies a model of urban development which takes ecosystems as their standard. However, building upon the understanding of an ecosystem, Barles (2010) and Broto et al. (2012), are of the opinion that cities are parasitic (ecosystems) that encroach on their surrounding habitats, polluting other resources (Barles 2010; Broto et al. 2012).

Urban metabolism consists of numerous interconnected processes with flows that are shaped by their historical, political, social and ecological contexts (Broto et al. 2012). These processes occur at “different spatial and temporal scales” (Kennedy et al. 2014: 8). The interactions between cities and their environments are inclusive of humans, and as cities urbanise, they become greater consumers of materials and energy. Pronounced trends of increased resource consumption in urban societies have numerous impacts on the city as an ecosystem, and have thus found renewed interests amongst various researchers across disciplines. Researches are interested in exploring the related issues of planetary capacity to maintain growing populations, and to halt the destruction of Earth's finite resources by people (Barles 2010).

2.3.2 Multi-disciplinarity within Urban Metabolism

Urban metabolism is a topic of interest across disciplines, albeit with varying approaches (Broto et al. 2012; Currie 2015). From the natural sciences, to the social sciences (Wachsmuth 2012), the complexity of the concept requires a host of diverse perspectives in order to fully comprehend its scope. The growth in literature and a related understanding of urban metabolism would lead to disentangling fundamental and complex challenges within cities (Kennedy et al. 2011; Broto et al. 2012; Zhang 2013; Currie 2015). According to Holmes and Pincetl, urban metabolism provides a "multi-disciplinary and integrated basis to examine cities' material and energy flows" (Holmes & Pincetl 2012: 2). Broto et al. (2012) points out that the plurality of approaches facilitates the understanding of certain perspectives within urban metabolism studies:

i. Environmentally charged models of development which learn from the analogy of a city as an ecosystem.
ii. Efficiency analyses of a city's material and energy flows.
iii. The extent to which an economy's material limits affects the ability for a city to achieve economic and resource stability.
iv. Influence of economy on flows between cities and rural areas.
v. Fair resource distribution for equal access across cities.
vi. Attempts at defining alternative visions for urban socio-ecological flows.

There are many facets to any city's sustainability. Urban metabolism serves to elucidate the distinctions and occasional overlaps that occur within the above-mentioned themes. This, in turn, helps to establish important dialogue between disciplines which can stimulate new approaches and address issues within sustainable urban planning (Broto et al. 2012; Chen & Chen 2015; Currie 2015). Chen and Chen (2015) argue that an integrated approach is required in order to understand urban metabolism at diverse scales. The 'wicked problems' within society (e.g. Terrorism; mismanaged urbanisation; lack of sustainability; global climate change, etcetera) can be addressed with help from a wide range of fields, such as "energy consumption, carbon emission, integrated water use, and regional sustainability" (Chen & Chen 2015: 3). Broto et al. (2012), contends that a diversity of studies is imperative in order to generate operative ideas for use in "policymaking, planning and design processes" for urban sustainability.

2.3.3 Approaches to urban metabolism

Recent literature on urban metabolism studies has birthed a methodological rationale (Barles 2010; Holmes & Pincetl 2012b; Ferrao & Fernandez 2013). According to Chen and Chen (2015: 1), urban metabolism is "proposed to analyse the energy and material flows of cities in quest of a better understanding of a sustainable urban system". There are a number of methodological approaches to analysing a city's metabolism. The three most commonly referred to are: material flow analysis; energy flow analysis; and ecological or environmental footprinting (Barles 2010; Kennedy et al. 2011; Broto et al. 2012; Chen & Chen 2015) in order to track the inputs, outputs and interactions of energy and material flows (Barles 2010; Kennedy et al. 2011; Broto et al. 2012; Chen & Chen 2015).

2.3.3.1 Material flow analysis

Material flow analysis (MFA) is the predominant method for assessing flows and stocks of materials in cities (Kennedy et al. 2011; Broto et al. 2012; Chen & Chen 2015). This material accounting approach was developed to assess the environmental impacts of the inputs and outputs in physical units (usually tonnes) for the sustainability of socioeconomic systems (Chen & Chen 2015). One of its objectives is to define the level of impact cities have globally, for example with resource availability, or air pollution.

2.3.3.2 Energy flow analysis

Systems ecologists began describing metabolism in terms of *energy*, specifically embodied energy (Conte & Monno 2012; Holmes & Pincetl 2012a). This approach recognised that there are various forms of energy flows in human societies, which arguably necessitated a universal metric in the form of solar energy equivalents (Kennedy et al. 2011; Broto et al. 2012). It was useful for comparing different flows using a single metric. The energy balance analysis is used to "assess the energy efficiency, resource renewability, and sustainability of a range of artificial systems" (Chen & Chen 2015: 3).

2.3.3.3 Ecological footprinting

Instead of focusing on the flows of substances through the city, ecological footprinting aims to quantify the amount of land required to "provide resources and absorb waste produced in a given territory" (Broto et al. 2012: 854). These 'footprints' define the evolving set of spatial dimensions and varying severity of a variety of metabolic impacts.

Understanding the different approaches to urban metabolism can assist in providing appropriate sustainability indicators to ensure the resource efficiency of cities.

2.3.4 Importance of urban metabolism

Ferrao and Fernandez (2013) describe metabolism as the processing of fuels and materials. Resources are extracted from the earth, and converted into suitable forms for building the physical urban fabric, and then released as waste (Ferrao & Fernandez 2013). A variety of resources are needed by cities: food, water, energy, goods and services. All of these resources are essential to its survival, and each forms part of the city's material flows (Lee et al. 2016). As the material and energy inputs required to maintain cities escalate, understanding of cities' metabolisms becomes critical (Holmes & Pincetl 2012). This is essential for providing the necessary framework for analysing energy pathways in order to increase resource use efficiencies and the conservation of energy. In fact, urban metabolism studies are developed from the growing understanding of the impending limitations on the use of fossil fuels and their impacts on the environment, as well as concepts of energy efficiency. Examining cities' metabolisms is essential for understanding and informing energy use in communities and finding opportunities for "energy efficiency, material cycling, waste management, and infrastructure" (Holmes 2012: 24). While urban metabolism studies are predominantly 'accounting exercises', they are vital to informing decisions regarding urban policy (Broto et al. 2012). To accomplish this, Kennedy et al. (2011) list four practical applications for the study of urban metabolism:

i. Sustainability indicators: urban metabolism studies offer relevant information about energy efficiency, material cycling, waste management and infrastructure, which are useful in indicating whether a specified region is sustainable.
ii. Greenhouse Gas Accounting: the amount of greenhouse gas (GHG) emissions can be estimated using urban metabolism information regarding energy consumption and material flows and wastes, in order to reduce them.

iii. Mathematical models: using technological interventions, these models can simulate alternative realities by altering the representation of city processes (inputs, stocks, outputs, with attached economic value) within the urban metabolism.

iv. Design tools: Oswald and Baccini (2013) suggest that urban metabolism studies can be used to redesign cities by considering four principles: “shapeability; sustainability; reconstruction; and responsibility”. In order “to nourish and recover; to clean; to reside and work; and to transport and communicate”. These major urban activities are assessed in terms of water, biomass, construction materials and energy (Kennedy et al. 2011: 1970).

The primary rationale behind the study of urban metabolism is to better understand and model resources (their availability and usage) within cities, in order address how they impact urban flows and other issues arising from their mismanagement (Mostafavi et al. 2014; Chen & Chen 2015; Lee et al. 2016).

Growth in populations across scale often dictates a proportionate growth in their related energy and housing demands. Cities with poor populations do not necessarily have the infrastructure required to “absorb expanding populations” (Turok 2014: 60). This aggravates the problems that the poor are already burdened with, such as overcrowding, related increase in health and crime risks, lack of affordable housing, and insufficient provision of or access to other services. Transcending the division between nature and society, the urban metabolism perspective has intensely politicised socio-ecological processes (Kaika & Swyngedouw 2011) as it falls within the greater sustainable development arena. This implies that urban metabolism is not complete without nature. Therefore, it is evident that a just socio-environmental perspective is required to marry nature and society. This will be further discussed in the following section.

When applying the concept of an urban metabolism to the built environment, the term is used to refer to complex collections of connected buildings, each defined by their own specific metabolisms (Conte & Monno 2012). The built environment results from an idiosyncratic blend of both global and local socio-ecological factors, not linked to any specific spatial scale (Conte & Monno 2012: 35), and will be discussed in more detail in section 2.4.

2.4 Sustainability in the built environment

A sustainable transition in the built environment is required, to ensure that the population and resources remain within the threshold limits and capacities of cities, or manage to grow *with* them. This section begins by exploring the evolution of the concept of sustainability, using sustainable development as a starting point. How sustainability can be interpreted within the built environment is explored, as well as how to determine when a building can be considered sustainable, and by whom. An overview of building rating systems is given, their relevance is discussed, and two characteristics that are vital for a constantly evolving built environment to progress sustainably are examined.

2.4.1 Evolution of the concept

Inspired by the Brundtland Report's definition of 'sustainable development' (WCED 1987), Elkington (1997) defines 'sustainability' as "the principle of ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations" (Elkington 1997: 20). In order to measure this principle, he articulated the phrase 'triple bottom line' (Elkington 1997). For a system to be considered sustainable, its economic, socio-political, and environmental dimensions, each with its own sets of rules and requirements, had to intersect and find a balance, as depicted in Figure 2.3 (a). However, while it was, no doubt, a pioneering concept at the time, the need for a more embedded description was recognized (Mebratu 1998; Hattingh 2006; Berardi 2013). Mebratu (1998) suggested that the problem arose with the representation of the triple bottom line where each line of thinking, or its dimensions, imposed its own systems of accomplishing a goal onto the others, in a reductionist fashion. To counter this, he proposed the concept of co-evolution of the natural and human universe, by way of his 'Cosmic Interdependence model' (Mebratu 1998). In this model, the four dimensions, or cosmoses (the ecological dimension is further broken down into an abiotic and biotic cosmos), are never mutually exclusive of one another, are no longer separate and independent of one another, but rather, are embedded within each outer sphere (Hattingh 2006). This alternative portrayal has been adapted and depicted in Figure 2.3 (b) below. This suggests the need for interdependence within these different dimensions, for a more realistic and *sustainable* model of sustainable development which in fact *relies* on these "interrelations between dimensions" (Berardi 2013: 73; GhaffarianHoseini et al. 2013; Hattingh 2006; Mebratu 1998).

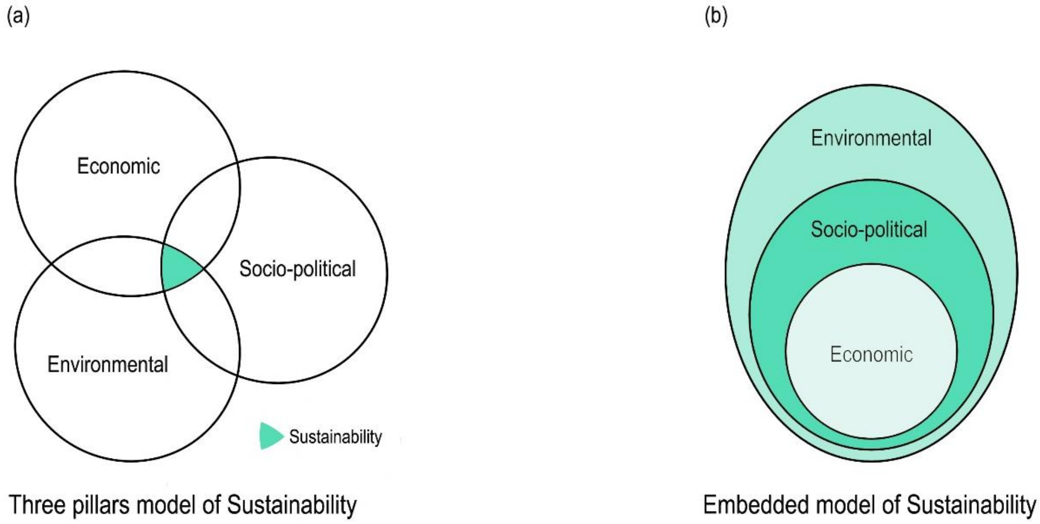


Figure 2.3 Transition from traditional to embedded model of Sustainability

(a) Traditional model of Sustainability; (b) Embedded model of Sustainability
Adapted from Mebratu (1998: 513) and Hattingh (2006: 210)

Moffatt and Kohler (2008) consider the built environment to be a complex social-ecological system, which according to du Plessis and Cole (2011), ranges across scales from materials to buildings to cities. Traditionally, the built environment is referred to as the "manmade surroundings that provide the setting for human activity, ranging from the large-scale civic surroundings to the personal places" (Moffatt & Kohler 2008: 249). Conte and Monno (2012: 31) refer to a conceptual model of such a social-ecological system, or built environment, as the *urban matrix*. In their description, the urban matrix comprises of buildings, each with their own specific contexts and metabolisms, interacting with one another to create a network of local and global social-ecological relationships (Conte & Monno 2012: 35).

Notwithstanding these differing conceptions of sustainability, and of the built environment, there is no universally accepted definition for sustainability *in* the built environment (Berardi 2013). Berardi attributes this largely to the lack of consensus on the term 'sustainable development', which, in spite of or because of this, has generated a global dialogue amongst both academics and practitioners. The built environment plays a vital role in the context of sustainable development in the face of global issues such as energy crises, GHG emissions, the long term impacts of environmental costs, and urbanization (Berardi 2013; GhaffarianHoseini et al. 2013; Moffatt & Kohler 2008). While all systems in the 21st Century are interconnected across different scales, sustainability should be contextually and locally specific (Berardi 2013). Similarly, GhaffarianHoseini (2013) argues that the built environment can only be deemed sustainable if the locally adapted attributes of the region in terms of its environmental, economic and socio-cultural and political concerns, are considered holistically. While Berardi (2013) claims that there is no universally accepted definition for sustainability in the built environment, principles as outlined by the International Council for Research and Innovation in Building and Construction below, and other world institutes and papers, suggests that a “common vision of sustainable building is emerging” (Berardi 2013: 76).

2.4.2 Criteria for a sustainable built environment

Figure 2.4 shows the criteria for sustainability that arise from four key factors in the built environment, namely to maximise economic gain; decrease resource consumption; maximise utility; and reduce environmental impacts. These four parameters determine the overall sustainability of a building within the *urban matrix*. This matrix refers to a conceptual model of the specific built environment (Conte & Monno 2012: 32), which emulates the metabolism of the city. The matrix, which could refer to the context of the city in its entirety, impacts each of the city’s functions or aspects, which in turn have an effect on the city as a whole, with special emphasis on its societal and spatial constructs. For example, water, energy, waste, buildings and people make up a city. Increasing the number of people would alter the amount of water, energy, waste and buildings available or required, which in turn alters the make-up of the entire city because all these aspects are interrelated.

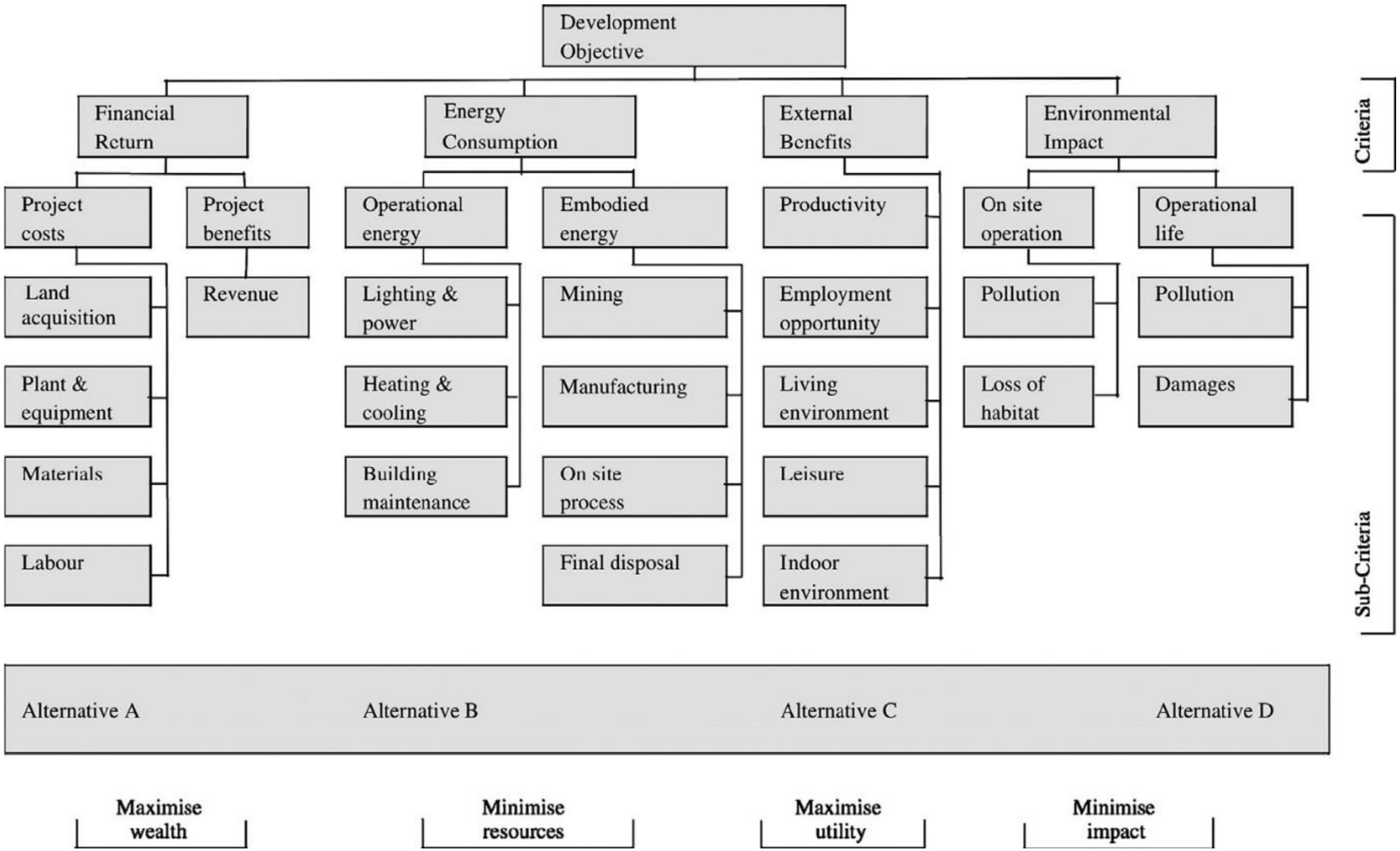


Figure 2.4 Key factors for a sustainable built environment

Source: GhaffarianHoseini et al. (2013: 4)

Conte and Monno (2012: 35) illustrate the relationships between buildings within an urban matrix differently. The building's performance influences how it interacts with its context and, at the same time, how this context informs the performance. According to Conte and Monno (2012), factors influencing building performance are categorised into four classes, namely: 'site', 'technical design', 'indoor and outdoor environment', and 'operation'. In terms of site, the indicators are site selection, development, urbanisation level, and integration of the urban context. Related to this is the density of development, and connections created within the community, usually by way of developmental nodes like recreational areas or cultural and commercial activities. Other indicators fall under the categories of ecological integration and infrastructural facilities, such as storm water design, landscaping, provision of public transport and sustainable alternatives to driving. Under the indoor and environment class, factors such as thermal comfort, daylight, acoustic comfort, factors which affect indoor air quality and reduce outdoor pollution, should be prioritised. The operation entails designing and redeveloping brownfield (urban) sites, integrating systems, and managing building services and maintenance.

Lastly, technical design considers energy requirements, materials used, and the use of water to influence resource consumption and environmental loads (Conte & Monno 2012).

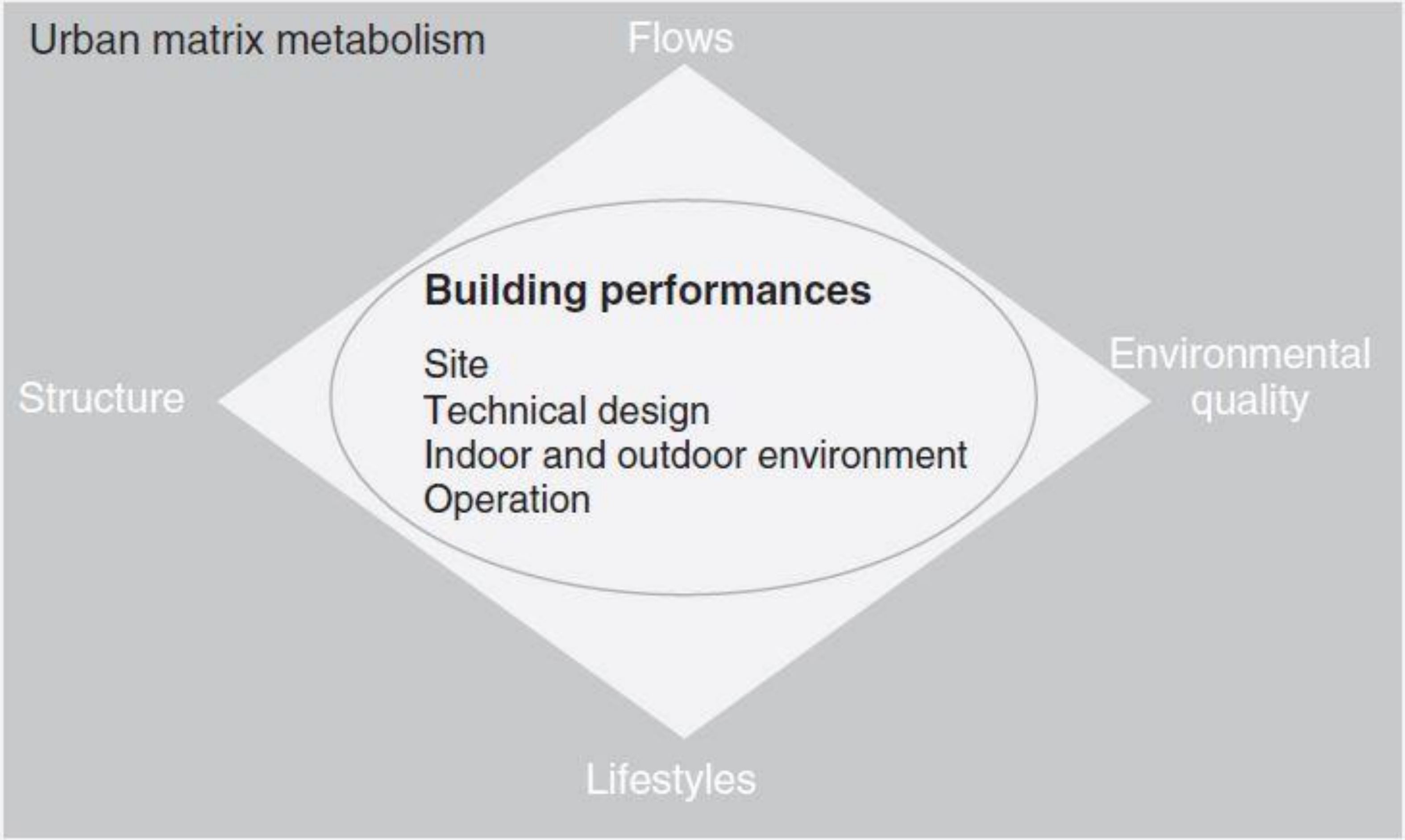


Figure 2.5 Buildings in the urban matrix

Source: Conte & Monno (2012: 35)

2.4.3 Building Rating Systems

The International Council for Research and Innovation in Building and Construction (known originally in French as the Conseil International du Bâtiment, or CIB) has identified ten principles for sustainable building. Similarly, there are numerous building rating systems around the world which attempt to ensure that buildings do not negatively affect their environments and communities, by setting guidelines and following rules very similar to the ones promoted by the CIB. Their ten principles for sustainable building are listed below (CIB 2010: 16):

i. Apply rules of sustainability, which recommend continuous assessment and improvement, equity, a holistic approach, long-term thinking, think-global-act-local, and a robustness and sense of responsibility in all actions.
ii. Collaborate with all interested parties, and be consistent and efficient through partnerships across all levels of building (design, construction, and maintenance).
iii. Use and connect to existing infrastructure: services; networks; grids.
iv. Design thinking about all phases of the construction process from concept to demolition, and evaluate performance at each phase (life cycle analysis).
v. Environmental impact should be minimized over entire service life of the building, taking into account local and global requirements, by being resource efficient and reducing harmful emissions and other waste.
vi. Economic value of buildings over time must not be ignored, and operation and maintenance, as well as renovation or demolition costs must be taken into account from the start.
vii. Sustainable buildings must have social and cultural value over time, and for their users.
viii. Health, comfort, safety and accessibility of space must be considered.
ix. The sustainable building must be: 1) user-friendly; and 2) incentivised to behave sustainably by understanding the thinking behind the building. In order for this to even be a possibility, the operation and maintenance instructions should be made available at all times.
x. Must evolve according to changing internal and external requirements throughout service life, that is, be resilient.

The last rule in this list is especially vital for the developing world, where built landscapes are constantly evolving and taking new shapes. The social and cultural arena, especially in South Africa, is changing, and needs a built infrastructure which complements this vision. As stated earlier, there are numerous building rating systems which rank buildings according to specific assessment criteria.

"If you cannot measure it, you cannot improve it" (Thomson 1891). These systems are increasingly useful when advising on building improvements, because they assess the overall environmental impacts of any building. Furthermore, they create awareness amongst built environment practitioners and building users alike. They encourage innovation, while still providing a framework for assessment. Achieving their best-practice ratings cultivates healthy competition, while, in turn, promoting sustainable building and practices. Assessment systems have also been known to inform policy implementation (Conte & Monno 2012). The most famous of these systems are: Building Research Establishment Environmental Assessment Method (BREEAM) which is prominent in Europe; Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) which rates Japanese buildings; Leadership in Energy and Environmental Design (LEED) which originated in the United States, but has since expanded its services geography; the Sustainable Building Tool (SBTool) developed by the International Initiative for Sustainable Built Environments; and Green Star, which began in Australia and has since been customised by over 100 national Green Building Councils (GBC's), including South Africa (Hankinson & Breytenbach 2013).

Even with their positive contribution towards holding the practitioners in built environments accountable, some practitioners might argue that these frameworks limit innovation due to their homogenisation (Conte & Monno 2012; Hankinson & Breytenbach 2013). They contend that the assessments are not interested in the urban matrix, but solely on the building – what Conte and Monno refers to as a *'building centric'* approach (2012: 32). Another recurring argument against rating systems is that they are predominantly score-based and driven by performance indicators which stress the importance of environmental conservation, but do not necessarily emphasise socio-economic well-being. While this might be true for most systems, the Green Building Council of South Africa has paved the way for inclusive design (GBCSA 2015). A joint project is currently underway between the World Green

Building Council and the South African leg to develop a socio-economic framework for projects.

2.4.3.1 Green Building Council of South Africa

By understanding the context of a developing country such as South Africa, with intense socio-economic challenges, the World Green Building Council emphasizes the need to expand the sustainability indicators in the built environment to more than just the environment. The new framework identifies key challenges, such as employment and economic opportunity; education and skills development; equality; health and safety; as well as community engagement and benefit, which can be addressed through design and construction (GBCSA 2013). The rating systems often assess buildings by their uses. The Green Building Council of South Africa specifically rates the following types of buildings by function: offices; multi-unit residential buildings; public and education buildings; and retail centres.

Each of these usage types are characterised by certain eligibility criteria, usually defined by spatial differentiation; space use; certain conditional requirements; a minimum number of dwellings, common property and government schemes. These building types are then rated based on whether or not they meet the numerous applicable credits under various categories, as determined by the Green Building Council of South Africa. For example, for multi-unit residential buildings in South Africa, the credits and categories outlined in Table 2.1 apply:

Table 2.1 Green Building Council of South Africa Multi-Unit residential assessment criteria

Multi-use residential buildings	
Category	**Credits**
Management	Green Star South Africa Accredited Professional; Occupant User's Guide; Environmental Management; Waste Management; Airtightness Testing; Common Property Rules
Indoor Environmental Quality	Ventilation; Daylight; Thermal Comfort; Hazardous materials; Internal noise levels; Volatile organic compounds; Formaldehyde Minimisation; Private outdoor space; Universal access
Energy	GHG Emissions – Heating and cooling; Energy sub-metering;

	Lighting energy use; Maximum electrical demand reduction; Hot water energy use; Common property services energy use; Low emission energy generation; Energy efficient appliances
Transport	Provision for car parking; Fuel efficient transport; Cyclist facilities; Commuting mass transport; Local connectivity
Water	Occupant amenity water; Water sub-metering; Landscape irrigation; Fire system water consumption; Potable water efficient appliances; Swimming pool/spa water efficiency
Materials	Recycling waste storage; Building reuse; Recycled content & reused materials; Concrete; Steel; Sustainable timber; Dematerialisation; Local sourcing; Efficient dwelling size; Masonry
Land use and ecology	Topsoil; Reuse of land; Reclaimed contaminated land; Change of ecological value; Urban heat island; Outdoor communal facilities; Urban consolidation
Emissions	Refrigerant/gaseous Ozone-Depletion Potential; Refrigerant Global Warming Potential; Insulant Ozone-Depletion Potential; Watercourse pollution; Discharge to sewer; Light pollution; Boiler and generator emissions
Innovation	Innovative strategies and technologies; Exceeding Green Star South Africa benchmarks; Environmental design initiatives

Source: Green Building Council of South Africa (2011)

By rating buildings across these types, using these criteria for their assessment, the Green Building Council of South Africa influences the sustainable transformation of the built environment. Employing the guidelines prescribed in their internationally acclaimed rating tools could prove useful in defining a starting point that will inform development in relevant policies, particularly in the energy sector. Renewable energy technologies and energy efficiency programs should complement one another. In order to reach international objectives of sustainable energy production and consumption, it is of the utmost importance that they are implemented simultaneously. Regardless of their focus, building rating systems do serve to condition the built environment to become more sustainable, by incorporating, for instance, energy efficiency within the environment. This will be dealt with in more detail in section 2.8.

2.4.4 Resilience and vulnerability

For the most part, the sustainability of social-ecological systems such as built environments are dependent on their ability to adapt to external and internal changes imposed upon them (Conte & Monno 2012). This is known as *resilience,* and it becomes an important parameter of scale in terms of rating the sustainability of a building, and a community (Conte & Monno 2012; Daniel & Ortmann 2011). Du Plessis and Cole (2011) support this claim that resilience is a key determinant for assessing sustainability in social-ecological systems such as the built environment. This concept of resilience under the sustainability paradigm is not a new one. According to GhaffarianHoseini et al. (2013), sustainability in the built environment should take into account the architectural evolution of the space. Due to the ever-changing nature of buildings and nature itself, criteria for sustainability should also evolve (Berardi 2013; du Plessis & Cole 2011). As a result, a key attribute of sustainable architecture lies in its ability to adapt to external and internal shifts in its contextual metabolism, over shorter and longer periods of time. The City of Cape Town relates resilience to the capacity “to absorb and respond to future shocks” and “maintain ongoing functionality” (City of Cape Town 2014: 9). In order to be resilient, a building or urban environment must reduce its own vulnerability, and adapt its metabolism to that of its greater context (Berardi 2013; Conte & Monno 2012).
In contradiction, Conte and Monno (2012) define vulnerability as “the susceptibility of the urban matrix with respect to harms produced from buildings, and indicates the absence of its capacity to adapt”. Between the definitions of the concepts of resilience and vulnerability, a range is created which enables dialogue within townships and the people engaging with them in an effort to assess and encourage their development. As explained earlier, changing the vulnerability or resilience of each building within its contexts by manipulating its performances can affect the metabolism of the entire building or urban matrix (Conte & Monno 2012).

The barriers found to have an impact on the implementation of sustainable design amongst built environment professionals were the following (Hankinson & Breytenbach 2013):

i. Cost: sustainable design projects are, on average, 10-20 percent more expensive and require higher upfront costs, despite offering long term savings. Furthermore, the projects often take longer to complete, because more research needs to be done, which increases the design costs.

ii. Education and inexperience: South African universities have yet to successfully integrate sustainable design into their curriculums. Experience seems to be limited in the field as well.

iii. Materials: product suppliers and manufacturers are often not transparent regarding the information they provide on their products, which makes it difficult for designers and builders to source or authenticate environmentally sustainable products. There is also a limited selection locally, which makes customisation difficult, and forces designers to import internationally – often rendering the product unsustainable due to the carbon footprint costs of flying.

iv. Client: clients are often wary of implementing sustainable design in projects due to the cost, lack of material and systems selection, and a lack of interest due to lack of education on the importance of sustainable development.

Sustainable building solutions for the urbanising population must be resilient, but also cost-effective, without diminishing quality of life for users. The issues range across income brackets and all building types, but make it especially difficult to implement sustainable design for low-cost buildings within townships, which is the specific focus of this study.

2.5 Low-cost buildings for urbanising populations of Africa

Once a group of farming and fishing villages, Lagos has grown to become the third largest city in the world (Salau et al. 2013; Adedayo & Malik 2015). In 2006, Lagos had a population of 17.5 million. It is the most populous city on the African continent and is currently estimated to be home to 21 million people, of which almost two-thirds live in slums (Agbola & Agunbiade 2009; Ibem 2011). According to Agbola and Agunbiade (2009), 606 people enter the Nigerian city each minute. However, because of Lagos' high rate of urbanisation, it is often difficult for population data to keep up to date. The growth in population also far exceeds the provision of affordable housing and sufficient infrastructure (Ibem 2011).

The Western Cape Provincial Government (2009) defines housing as "more than just shelter as it determines an individual's access to other services and facilities, like schools, clinics, job opportunities and shop. The location of housing 'defines the geography of opportunity"(Western Cape Provincial Government 2009: 2). For example, the location of low-cost housing on the periphery of Lagos city has often been deemed unattractive because it is so far away from the users' places of work within the city (Olotuah 2015). It is not enough simply to create enough houses, but it is imperative that these homes are also "linked to infrastructure and services that enable people to enjoy their community, to live effectively, and to work efficiently" (Jeddah Economic Forum 2013: 10). Housing quality is context-specific.

Sengupta and Tipple (2007) contend that the indicator variables that grade the quality of low-cost housing are different to the ones used for the houses belonging to medium or high income user groups. The fundamental criteria for quality low-cost housing relates to the cost of the house; comfortable occupancy rates; permanence and integrity of structure; connections to all basic services and recreational or community facilities; as well as location, which allows for integration with the rest of the city (Sengupta & Tipple 2007; Ilesanmi 2012). For housing to be affordable, they consider three parameters: the initial cost of the building, the annual household income, and the annual rent (Olotuah 2015). Households must be able to meet their housing (construction/upfront) costs as well as their basic costs for living (AHURI 2004).

In Lagos, public housing is often very expensive for most low-income earners. Initial efforts to address the housing deficit were made by the colonial government of Nigeria in 1928. However, the most significant contributions were made after the creation of the Lagos State almost forty five years later, when the Lagos Executive Development Board, the Western Nigerian Housing Corporation and other district authorities joined together to establish the Lagos State Development and Property Corporation (Ilesanmi 2012; Ibem 2011). Despite government funding, the Lagos State Development and Property Corporation failed to meet the affordable housing requirements of the city, but has since contributed a considerable amount to Lagos' urban housing stock (Ilesanmi 2012). The typical low-cost house was a semi-detached structure consisting of one bedroom, which could then be extended by the owner when they could afford to, or when it was needed (Olotuah 2015). Three-bedroomed houses were constructed for people in higher income brackets. The Lagos State-funded Millennium Housing Scheme, which aimed to build 45000 low-cost houses between 1999 and 2007, was found to have achieved less than 5% of their target (Ibem 2011). The public sector has consistently failed to provide affordable housing for low income earners. The need for private-sector funding, and then specifically public-private partnerships (PPP), was realised when the economic recession hit the country. Currently, the most active sector funding housing for Nigeria's urban poor is the informal private sector (Olotuah 2015).

As with many African countries, the issues in Nigeria with regards to providing affordable social housing, are due to inconsistent or ineffective housing standards that do not prescribe the required quality, as well as a lack of assessment tools needed to evaluate the quality of built structures within a developing country context (Ilesanmi 2012). Other factors include lack of relevant data, poor or no implementation of existing policies, frequent institutional changes, and corruption, especially within the government domain (Ilesanmi 2012).

2.5.1 Low-cost buildings in South Africa

As explained in section 1.1, the 'urban' areas in which these low income citizens often find themselves are hardly as ideal as they might have imagined when leaving their homelands. The urban peripheries of cities in South Africa have rudimentary infrastructure (Mbonyane & Ladzani 2011; Todes 2012; Jürgens et al. 2013), and make it nearly impossible for the communities in these areas to improve upon, or rise above, the economic circumstances they find themselves in. Their marginalised position is further exacerbated by expensive transport costs needed to gain access to the city from their location on the periphery, leaving them financially vulnerable, and unable to access necessary urban amenities. As the rate of urbanisation increases exponentially, the need for socially and economically viable forms of housing intensifies. Increases in city population results in largely inefficient, and inequitable cities with poor periphery townships and settlements battling the most severely entrenched trends of poverty (Goven et al. 2012). The possibility of tackling the existing housing backlog is compromised through the crippling growth of sheer urbanisation-related housing demand. Affordable housing projects attempt to close this gap. As an example of low-cost buildings, social housing (used interchangeably with low income housing) is broadly limited to low-income users with a combined household income of less than R7500 per month (Statistics South Africa 2012). For the purpose of this study, all buildings within townships are considered inherently low-cost. As with informal settlements, which are often found within township borders, these townships were "racially discriminatory" (Bond 2008: 405) and have a mixed demographic in terms of economic profile. Most, however, are predominantly low-income households (Swilling 2006). In order to determine whether a suburb is a township, a benchmark average monthly household income below R3200 per month was used. Census (2012) defines this amount as South Africa's poverty line. The Department of Human Settlements (2015) reports that 44% of South African households earn below the poverty line. Of this percentage, 37% own formal housing, 30% rents a formal space which is not in a backyard and another 12% own or rent within informal settlements. The last 21% of citizens who earn less than R3200 live in informal conditions (National Department of Human Settlements 2015: 6), and therefore do not apply to this study. The focus of this study is on the current situation of low-cost buildings in South Africa, especially the townships of Gugulethu and Manenberg in the City of Cape Town.

Rapid urbanisation post-Apartheid has resulted in more than half of South Africans living in urban settlements (Goven et al. 2012: 186). However, with fluctuating demand, and increased rates of urbanisation, the national housing deficit, which reflects the portion of the population in need of low-cost housing, has remained stagnant since 1994 (Bolnick 2010; Department of Human Settlements 2009). The Annual Performance Plan indicates that high unemployment, inflation, high building costs, an unstable financial environment, and the related inability of low income earners to access credit, are factors that impact development in this sector (National Department of Human Settlements 2015). Statistics South Africa (2014a) reports that 1 358 000 and 700 000 households respectively, live in shacks and backyards in informal settlements, and that approximately 7 million people live in Reconstruction and Development Programme (RDP) or state-subsidised houses. The average size of a state-subsidized house is 36m², and comprises two bedrooms, a toilet, and a kitchen (Bolnick 2010). The houses are constructed primarily of conventional building methods using brick and mortar. 10% of the national housing budget each year is currently being allocated to the deconstruction and reconstruction of badly built houses that are deemed uninhabitable by the housing examiner's office. The houses are often so poorly insulated, with such little consideration for thermal performance, that occupants have to use up to a fifth of their disposable income on heating alone (Streeter & de Jongh 2013).

Although it has been recognised conceptually in various studies, that it is financially and environmentally more beneficial to develop houses in different provinces according to locally available and recycled materials (Birkeland 2008; Omer 2008; GhaffarianHoseini et al. 2013;

EThekwini Municipality 2013), state-subsidised housing programmes have yet to put this into action.

The development trend in South Africa has been influenced by the UN-Habitat and World Bank Millennium Development Goals (MDGs) of improving the lives of at least 100 million slum dwellers by 2020 (UNDESA 2011). The MDGs have since been replaced by the Sustainable Development Goals (SDGs). Goal 11 of the 17 new goals focuses on Sustainable Cities and Communities and is most applicable to this study. The aim is to make cities and human settlements inclusive, safe, resilient and sustainable. The revised target within this goal aims to ensure that everyone has access to adequate, safe and affordable housing and basic services, and to upgrade slums by 2030 (United Nations 2015). The overall agenda of this goal is to "make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations 2015: 14). The old goal to uplift 100 million slum dwellers was commendable. However, the implementation of such a goal contained the negative implication that the slums needed to be eradicated, versus the idea that the lives of those living in these slums could be improved (Huchzermeyer 2006).

The notion of incrementalism, explored by Swilling and Annecke (2012); Abbot (2002); and Parnell and Pieterse (2014), was introduced to curb this problem. Incrementalism, which falls within the lens of ecological design, refers to a process of gradually increased awareness of the energy and resource flows and other social capital which maintain a community. This kind of process can only be implemented with active involvement from all members (Van Der Ryn & Cowan 1996). Specifically, in informal settlements, this refers to the in situ upgrading of settlements, instead of relocation (Department of Human Settlements 2009; Huchzermeyer 2006). Following this approach, communities tap into formal flows and create their own informal flows out of necessity. Although shelter is a basic human right, many of the existing and proposed low-cost housing solutions do not pass even national building standards. So, while it is all very well to want formal planning systems, some of them do not even conform to the country's own standards. Abbott (2002) proposes that an incremental, well-structured method-based approach made up of a logical set of interrelated actions and internal social cohesion should be defined and employed, in order for the given settlement or system to become a self-sustaining element of the greater urban fabric. Over the long term, this can then be replicated, as the context permits. Concepts such as that of high-density living, and compact cities with efficient transport flows, diversified and resilient spaces made up of mixed-use and affordable housing, are generally considered when planning the future of urban developments. It is, however, fundamental to the success of any community's design that the immediate and historical, tangible and intangible contexts be considered. In summary, this study argues for the need to explore the ingenuity and ability of slum and township dwellers to improve their homes and communities instead of displacing them.

2.5.2 Buildings within townships of the City of Cape Town

The location of Indian, Coloured and Black townships around Cape Town's city centre can primarily be attributed to the forced removals and segregation politics under the Group Areas Act (Act 41 of 1950), and the Group Areas Amendment Act of 1963, testimonies to the Apartheid government's plan to "divide and conquer" (Ahluwalia & Zegeye 2003). This act was supported by the ruling party of the time, which stated in it policy that, "Group Areas exemplify the fundamental tenet of Apartheid ideology that incompatibility between ethnic groups is such that contact between them leads to friction, and harmonious relations can be secured only by minimizing points of contact" (Jacobs 2010). During this period, the act drove the residential segregation of people from different racial groups: White, Indian, Coloured and African people were separated into different areas, and non-White people were prohibited from owning land in 'White' areas (Seekings 2011).

The forced removals to the Cape Flats and similarly impoverished areas tore the social fabric of communities, creating insecurities stemming from disconnect from established familial and friend networks. In fact, the housing units were often designed to serve only single people or nuclear families, which lent to the destruction of the joint-family philosophy embedded in the cultural practices of removed populations. "Relocations were organised in such a way that a form of social apartheid was superimposed on apartheid *per se*" (Martin 1999: 148; Ahluwalia & Zegeye 2003). Many of the formal buildings within these sterilised and intentionally poorly serviced townships were designed by the Apartheid state without consideration for their daily users and inhabitants. They were built to ensure security and control, not to provide happiness, or to ensure the health of the residents (Oldfield 2000).

The uniformly engineered, concrete and masonry-clad landscape and limited vegetation in the 'matchbox' sized designs dispelled any sense of privacy between occupants within a house, and their neighbours (Ahluwalia & Zegeye 2003; Lee 2005; Staniland 2011). Houses were built without ceilings, floors, or internal doors, and bathrooms were often outside structures – again, the concept of privacy was blatantly disregarded (Lee 2005). No family housing was built for Africans working in Cape Town to ensure that their movements could be effectively monitored (Ahluwalia & Zegeye 2003). Instead, migrant workers were housed in predominantly single-sex dormitories known as *hostels*, which will be discussed in more detail in 2.5.2.9. The layout of the townships was organised in such a way that they could be easily policed, controlled and regulated (Oldfield 2000; Ahluwalia & Zegeye 2003; Lee 2005). The dehumanizing designs of these buildings continue to create intransigent problems in terms of upgrading (Home 2000).

Currently, the City of Cape Town is one of South Africa's largest cities. As such, it still experiences high volumes of in-migration from other provinces, especially in-migrations of unemployed people from the Eastern Cape (Tredoux 2009; HDA 2013; M Swilling 2006). Tredoux (2009) suggests that it is primarily due to these migrations that the City of Cape Town municipality has experienced a considerable backlog of formal housing. While the process of formalising housing has not yet been agreed upon in this municipality, a growing number of people appear to be living in informal dwellings (Tredoux 2009; HDA 2013; Maqetuka & Muller 2012). The population of the City of Cape Town is 3 740 025, with net in-migration of approximately 50 000 people per year (Statistics South Africa 2012). There are 1 068 572 formal households in the municipality, of which approximately 232 027 are considered indigent (Maqetuka & Muller 2012; Statistics South Africa 2012).

Muringathuparambil (2014) believes that there is a need to consider the projections for City of Cape Town's population under existing urban conditions, in order to estimate the proportion of the population which would need to be serviced by (low-cost) housing. The City of Cape Town's study has shown that an in situ upgrade of all 230 of the city's informal settlements, not including the upgrades required in townships, would cost in excess of R19 billion (Maqetuka & Muller 2012). This presents the municipality with a challenge rooted in both economical (rising land and construction costs), and environmental concerns. Increased energy waste, land occupation and GHG emissions from unsustainable, irresponsible building practice reduces the motivation for government and private investments into these settlements. Essentially, if buildings are not built in an environmentally responsible way that takes energy systems, materials, water recycling systems, thermal comfort measures and other such aspects into consideration, it will undermine all possible future investments into the space.

As the various types of buildings found in these townships are not documented, it is difficult to extract information regarding the processing of flows. However, some of the types of buildings found within Cape Town's townships are described below.

2.5.2.1 Informal dwelling

Shacks and backyard dwellings (shacks built in formal buildings' properties), also known as '*hokkies'* are informal structures that are not recognised by the municipality and are therefore not afforded government services or infrastructure (McGranahan & Satterthwaite 2003; Lemanski 2009). As such, they often share the services afforded to the formal buildings (Lemanski 2009). They are usually constructed illegally by township residents using available scrap material, and in order to extend space in otherwise crowded city-funded buildings (Lemanski 2009). No prescriptive design or materials are used in the construction of these shacks. Designs are based on need, and materials used are based on availability (Lemanski 2009; Teppo & Houssay-holzschuch 2013).

Photograph 2.1 Shacks and backyard dwellings, Gugulethu

Source: Author

2.5.2.2 Non-residential buildings

Churches, schools, community centres and shops, both formal and informal, are scattered throughout the townships (Teppo & Houssay-holzschuch 2013). Clinics and other multi-purpose/mixed-use venues (school halls that serve the community for events, church services, and community meetings) are also common (Donaldson et al. 2013). Some of the townships boast shopping centres, and architecturally acclaimed buildings designed by famous South African architects – however, this is by no means *common* (Teppo & Houssay-holzschuch 2013). Most buildings in this category adopt masonry and concrete structures, with corrugated roofs and single stories.

Photograph 2.2 Church, Gugulethu

Source: Author

2.5.2.3 Government temporary housing

Temporary relocation areas, also known as ‘transit camps’ or ‘decant camps’, are camps which provide improvised, temporary accommodation for residents either being evicted from their state provided homes, or for those who are in need of accommodation while their state homes are being ‘beautified’ (Ranslem 2015). Often, these structures become the residents’ permanent homes (Middleton 2010; Ranslem 2015). Electricity and sewage systems are installed in most cases, with some temporary relocation areas making use of solar water heaters (Housing Development Agency 2012; City of Cape Town 2015a). Situated away from key urban amenities and places of work, the temporary relocation areas had previously been built from corrugated iron containers (as seen in the photograph below); Nutec (timber product typically associated with Wendy houses) and other weather resistant materials (Middleton 2010; Furlong 2015; Ranslem 2015; Maregele 2015). They range in size, but are typically smaller than your average Reconstruction And Development Programme House, even though most accommodate more than a single family each (Housing Development Agency 2012).

Photograph 2.3 Government temporary housing, Manenberg

Source: Author

2.5.2.4 Rowhouses

The rows of cheaply built, oppressively compact, uniform state houses, known formally as Non-European (NE) 51/6s (which translates to 'Non-European' version 6, built in 1951), were introduced by the then National Building Research Institute for mass roll-out during the implementation of the Group Areas Act. They later became known formally as 'rowhouses' (Oldfield 2000; Lee 2005; Gospodini et al. 2008; Wainwright 2014), and colloquially, as 'garages' (Mdayi 2016; Malebo 2016). The original designs consisted of 2 bedrooms, a living room and a kitchen-dining area, with a backyard toilet, and walls shared with adjacent (row) houses (Lee 2005).

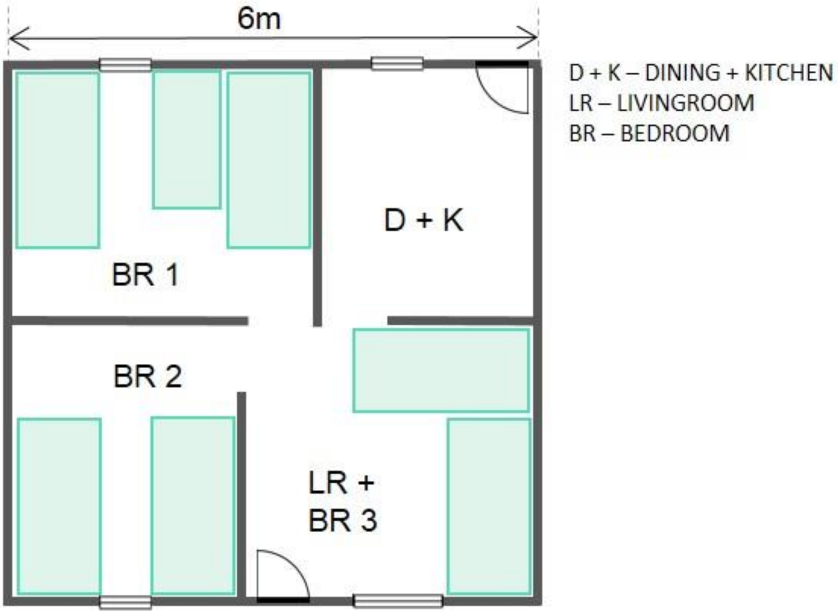


Figure 2.6 Original concept for NE 51/6 Rowhouse

Adapted from Lee (2005: 622)

They were made of brick and sometimes concrete block, and had no floors, ceilings, internal doors (just openings), but had asbestos sheet roofing (Lee 2005). They have been referred to as ‘stables’, ‘dog kennels’, and ‘matchboxes’, amongst similarly degrading names (Lee 2005; Tonkin 2008; Teppo & Houssay-holzschuch 2013; Wainwright 2014).

Photograph 2.4 Single storey rowhouses, Gugulethu

Source: Google Earth (2016)

2.5.2.5 Maisonettes

Maisonette buildings, also known as the ‘infill scheme’ in Manenberg, were usually configured in simplexes or duplexes (Tonkin 2008; Jacobs 2010). They are a type of low rise high density typology, which make use of sand bricks as their base construction, with face-brick cladding on the exterior (Jacobs 2010). They are usually designed to have a living room, kitchen and one bedroom on the ground floor, and two bedrooms and a bathroom on the first floor (Jacobs 2010). Even though they have an upper level, they are not particularly spacious, and the shared walls between neighbours negatively influence levels of privacy. They were, however, considerably superior to the other types of housing made available to residents in Manenberg specifically (Jacobs 2010).

Photograph 2.5 Maisonette House, Manenberg

Source: Muringathuparambil (2016)

2.5.2.6 Cottages

The cottages are single storey and semi-detached, only sharing a wall with one neighbour unit (as opposed to the rowhouses) (Home 2000; Jacobs 2010). They had two or three bedrooms, a living room, kitchen and bathroom. These cottages were limited to residents who earned a comparatively higher salary within the subtler economic hierarchies within the townships of Cape Town (Jacobs 2010).

Photograph 2.6 Cottages, Manenberg

Source: Google Earth (2016)

2.5.2.7 Courts

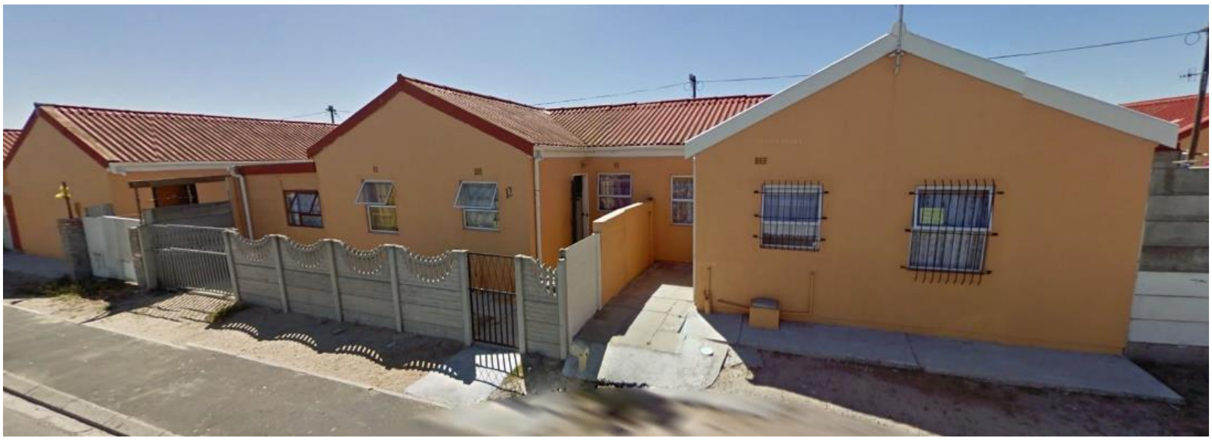
The three-storey courts go by many names: ‘*korre*’ to the residents, ‘tenement buildings’ or ‘walk-up buildings’ to academics, and the notorious ‘Flats’ – of Cape Flats-fame (Ahluwalia & Zegeye 2003; Swilling et al. 2011; Tonkin 2008; Jacobs 2010). They are a high density housing projected which was constructed to accommodate the Coloured people forcefully removed from District Six (Ahluwalia & Zegeye 2003; Jacobs 2010). The first flats were built in Manenberg in 1966 (Jacobs 2010). They are designed to be policed, with buildings in units of two, placed five metres apart and fenced, with each building containing approximately 18 two-bedroom units, while housing a considerably higher number of households within each unit. The space between the two buildings is devoted to strings of washing lines, play areas, and parking, eerily similar to a jail yard (Ahluwalia & Zegeye 2003; Tonkin 2008).

Photograph 2.7 Courts, Manenberg

Source: Author

2.5.2.8 Government Reconstruction and Development Programme House

The Reconstruction and Development Programme (RDP), and the more recent 'Breaking New Ground' plan, aim to provide public housing through *sustainable* human settlements for *sufficiently* poor (eligible) South Africans (City of Cape Town 2015a; Dubbeld 2007; Lemanski 2009). In practice, however, the poorly built Reconstruction and Development Programme houses were similar to other low-cost government building typologies within townships, and rarely conformed to energy efficient regulations regarding orientation, a sufficient roof overhang, or the need for insulation or ceilings (Dubbeld 2007; Sustainable Energy Africa 2014b). These houses are typically around 30m², with one room and a toilet, and built with concrete blocks or brick masonry, and corrugated iron roofing (Lemanski 2009). Again, the lack of privacy and space is highlighted, which results in informal backyard dwellings which provide extra space. Since then, newer models have improved thermal performance and offer water heating through roof mounted solar water heaters, and are correctly orientated (Sustainable Energy Africa 2014a). Most initial buildings were single detached units, but more recently, the programme is increasingly adopting the duplex and semi-detached approach, which minimises material usage and exterior wall exposure through shared wall space (Sustainable Energy Africa 2014b).



Photograph 2.8 Government Reconstruction And Development Programme House, Manenberg

Source: Google Earth (2016)

2.5.2.9 Migrant labour hostels

African men who came from the homelands in search of work in the city were not allowed to occupy space there (Goodlad 1996; Tomer 2014). Instead, they were forced to live on the periphery of the city, in under-serviced, overpopulated migrant labour hostels – colloquially referred to as 'zones' or '*KwaKiki'* (Selvan 1976; Ramphele 1993; Staniland 2011). These hostels came in single storey (usually made of masonry brick), and two-storey versions (sand bricks). Their dimensions, however, were not precisely uniform (Ramphele 1993). They were built either by city employers, or by the state (Selvan 1976; Ramphele 1993; Staniland 2011). The buildings were dormitory-style, single-sex labour compounds, that introduced the notion of a 'bedhold': a worker's home *was* his bed (Tomer 2014; Ramphele 1993). Once the Pass Laws were repealed, women, children and extended family were allowed to join the original male residents, regardless of a lack of extra space (Tomer 2014; Selvan 1976; Ramphele 1993). This is not to say that there were no women or children in the hostels before, only that now they could now legally be there, and share the bedhold. Ramphele (1993) notes that each 'door' (a unit which represents a house due to a single *door* separating a varying number of rooms with beds from the outside) had an occupancy rate of approximately 2,8 people per bed (Ramphele 1993). An example of a hostel door, adapted from plans provided in Ramphele (1993) and Selvan (1976), can be seen in Figure 2.7.

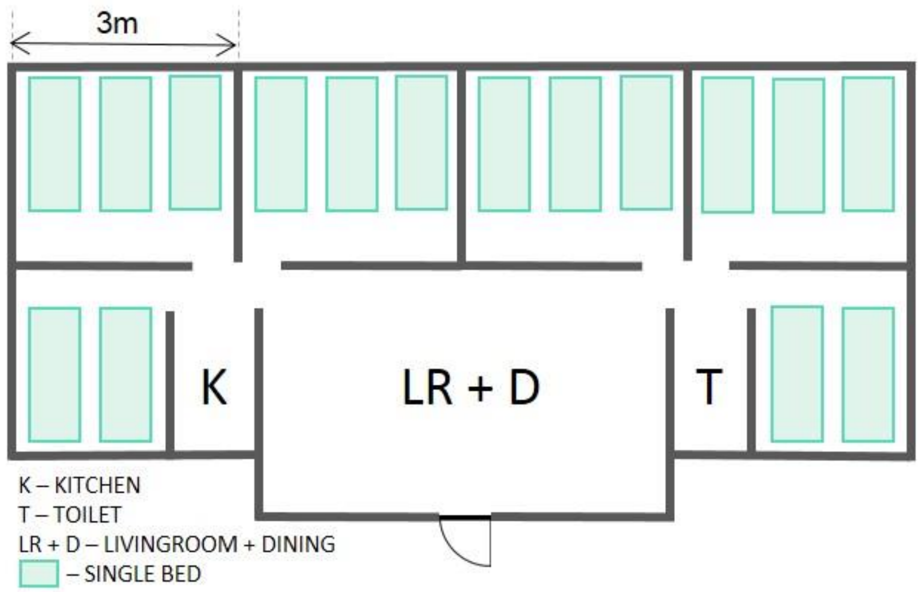


Figure 2.7 Hostel 'door'

Adapted from Ramphele (1993: 23) and Selvan (1976: 21)

As can be seen in Figure 2.7, each unit consisted of two rooms with two single beds each, four rooms with three beds each, a toilet and a kitchen. The 'front room' was originally meant to be a dining area and lounge space. However, with the excessive occupancy rates, this room was usually occupied by teenage boys and single adults (Ramphele 1993). Using the same occupancy rate, the bathroom and kitchen effectively serviced ± 45 residents. Most of the single storey hostel buildings in Gugulethu comprised two such units separated by a shared wall (Selvan 1976). The single-size beds were usually made of wood or concrete, and did not include a mattress or bedding. These are usually altered for comfort at the residents' expense (Selvan 1976; Ramphele 1993). The floors provided were made of concrete, but again, these were usually modified. Sometimes, they were covered in rubber tiles (Selvan 1976). There were no ceilings, and no internal doors (Selvan 1976; Ramphele 1993). Some of the hostels, like the longer single-storey hostel from Gugulethu depicted in the photograph below, had a few more 'doors' attached.

Photograph 2.9 Migrant Labour Hostel - 1 storey, Gugulethu

Source: Author

The newer two-storey hostels (seen in Photograph 2.10) follow the same design as the standard two-unit single storey ones, except that these buildings have double the number of units: two doors on top, and two below (Selvan 1976). The material change is only in the type of wall construction which uses sand brick, while the dismal quality of construction remains. Between hostels, one can find washing lines and parking areas (Ramphele 1993).

Photograph 2.10 Migrant Labour Hostel - 2 storey, Gugulethu

Source: Author

2.5.2.10 Private residential house

After 1994, people were allowed to buy land and formally build their own homes wherever they could afford to. Amongst the council homes and informal dwellings, one can see a myriad of housing styles using a variety of materials and designs. These homes are usually of a superior quality construction, even though most remain modest in design. If they could afford to, homeowners usually adopted design practices which were lacking in their previous homes or shacks, such as ceilings and insulation, and shading, as required.

Photograph 2.11 Private residential house, Gugulethu

Source: Google Earth (2016)

2.5.2.11 '2-storey'

'2-storeys', as the residents refer to them, are council-owned double-storey rowhouses, most prominent in Manenberg. According to Pascoe (2016), these buildings typically have three smaller flats on the ground floor, and two flats on the top floor, accessed by stairs on the outside. The units are separated by a thin single-leaf brick wall, which offers no privacy between neighbours. The smaller flats generally have a living room-cum-bedroom, a kitchen, and bathroom, or a bedroom, separate living room, kitchen and bathroom. The flats at the top have a living room, two bedrooms, a kitchen and a bathroom (Jacobs 2010). These buildings were built using masonry brick, are not insulated and have no ceilings. The original buildings were not plastered, but were given a thin layer of paint. They did not have internal doors, and doorframes were not provided for external doors either (Jacobs 2010; Pascoe 2016). The roof is still covered with asbestos sheeting, which Pascoe (2016) believes is the reason for the chronic asthma of many children. .

Photograph 2.12 '2-storey', Manenberg

Source: Holder (2016)

2.6 Typology of buildings

While typologies exist in and for cities all over the world, the majority of them are focused on countries of the Global North. Regardless, this study considered these typologies, bearing in mind that the criteria which established these typologies needed to be customised to suit the African and Global South context. Categorising townships and types of buildings present there according to their consumption behaviours, reduced the need to investigate individual townships and settlements.

2.6.1 International building typologies

Internationally, the use of typologies for building studies is not uncommon. However, one of the main challenges of urban sustainability would be to address the most critical elements of *types* of cities (Ferrao & Fernandez 2013).

A project worth referencing is the Typology Approach for Building Stock Energy Assessment, or *TABULA* project (Dascalaki et al. 2011; Intelligent Energy Europe 2012a; Corgnati et al. 2013; Kragh & Wittchen 2014; Wong 2014) which was later built upon by Energy Performance Indicator Tracking Schemes for the Continuous Optimisation of Refurbishment Processes in European Housing Stocks (EPISCOPE) project. Both these projects were co-funded by the Intelligent Energy Europe Programme of the European Union, in order to ultimately meet the climate protection targets set for Europe. In the original project, 13 countries participated, resulting in national residential building typologies for each. These typologies classify and group the buildings according to certain criteria (building age, size), and from this, a set of 'exemplary buildings' is presented. The project is considered to be robust in its operation, as there is a readily accessible 'TABULA WebTool' which provides online reference calculations for each of the national ideal buildings, and their cross-country comparison, as well as published 'Building Typology Brochures' that are standardised throughout the programme, except for their languages of publication (Intelligent Energy Europe 2012a). The concept for the TABULA Typology structure follows a two-track process. The first is informed by the individual country's national regulations and language, as well as the national experts in these fields. The second or concurrent process is reliant on transparency between countries, and uniformity of the calculation process; the classification system, data structure and energy balance. This concept is illustrated in Figure 2.8.

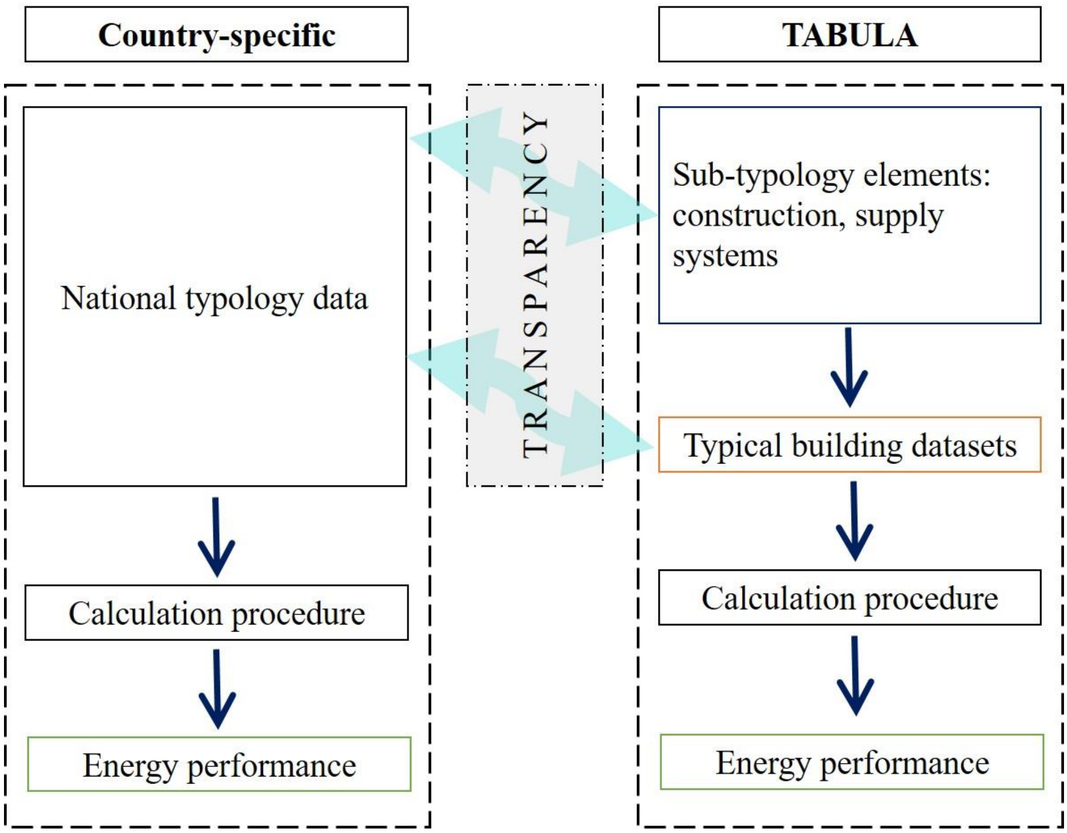


Figure 2.8 TABULA Conceptual Typology Structure

Adapted from Intelligent Energy Europe (2012b)

The EPISCOPE project objective was to "make the energy refurbishment processes in the European housing sector more transparent and effective" (EPISCOPE 2013: 1) by building on the conceptual framework developed by the TABULA project. This project expands the scope of the project, including 6 new countries and incorporating new sustainability standards with regards to Nearly Zero Energy Buildings (nZEBs), resulting in national typologies for 16 countries across Europe. This term is often used interchangeably with "energy efficient buildings" (Krog 2015). The Energy Performance of Buildings Directive requires that all new buildings must be Nearly Zero Energy Buildings by the end of 2020 (The European Parliament and the Council of the European Union 2010).

Dascalaki et al. (2011) look at the Hellenic building stock to evaluate the use of the TABULA building typologies for assessing energy performances of residential buildings. Similarly, Kragh and Wittchen (2014) review the Danish models, which are exemplary and an average model, focused on energy performance. All the TABULA building types have essentially been classified based on three factors: size, construction period, and climatic zone. Filogamo et al. (2014) and Krausmann et al. (2008) argue that country-specific data is often not representative of an entire country due to the diversities within cities, as in the example of Italy which has construction periods ranging over 105 years, and six climatic zones – half of which are represented in the TABULA Italian typology.

In Australia, Wong (2014) claims that there has been no robust attempt at generating representative building designs for energy efficiency policy. Wong developed a typology of representative dwelling designs using both statistical and qualitative data, in order to produce floor plans and dwelling descriptions that are representative of Australia's residential built environment and would ultimately inform strategies for improving building energy efficiency, and meeting national environmental targets.

While it is important that typological studies are conducted at country- and city-level, the challenge presented by developing nations indicates a lack of data in the informal urban settlements found within these regions. Thus, it remains essential to consider the perspectives of developed versus developing urban contexts (Ferrao & Fernandez 2013: 204).

2.6.2 South African building typologies

It was important to look at work conducted globally, especially in countries of the Global North, in order to generate ideas that are context-specific, and applicable to South Africa. Some of these precedents may provide prevention theories and solutions to historical problems. Technologies can be customised to serve South African infrastructural and resource needs in new and innovative ways (Ferrao & Fernandez 2013). Examining the typologies of buildings in townships and informal settlements, a step relevant to the energy resource consumption due to material, size, and locational attributes and severity of informality in developing contexts, can offer insights into alternative energy conservation methods in social building construction.

There are very few existing typology studies in South Africa. Storie (2012) developed low income settlement types that were aimed at creating awareness about the dangers of building them on dolomitic ground. Ten different settlement types were identified using aerial photographs, which illustrated the risks of dolomitic ground, but also the common feature of informal infill-housing between subsidised housing. The typologies highlighted the differences between the types, and provided insights on initiatives to manage the risks.

The District Six Development Framework drawn up by Mammon et al. (2010), explored various housing typologies suitable for the District Six site, preferred build fabric, preservation of views, and its capacity. While not limited to these, the four housing typologies identified were row (terraced) houses; courtyard houses; stepped housing; and perimeter apartment block housing. This is a different approach to the low income settlement types in the Gauteng City-Region Observatory (Storie 2012) and the housing typologies identified within the Thekwini Municipality (eThekwini Municipality 2013) which observe the condition of existing buildings. In this case, the context is considered, and typologies suggested in order ensuring that District Six becomes a fully integrated development.

EThekwini municipality (2013) has also developed a housing typology. The primary objectives of this typological study was “to inform the optimisation of quality and sustainability in the design and ongoing delivery of subsidy housing” (eThekwini Municipality 2013). By doing this, the study aims to propose housing typologies most suitable for application within informal settlement upgrades in their context.

To the researcher's best knowledge, this is the first typological study gathering data on building energy consumption within the City of Cape Town's (or South Africa's) townships and informal settlements.

2.7 Energy in South Africa

"Sustainable development is highly intertwined with the deliberation of energy (GhaffarianHoseini et al. 2013: 2). South Africa is an energy-intensive emerging economy, which unfortunately still extracts raw materials for external consumers" benefits (Department of Energy 2013a; Sustainable Energy Africa 2014b). As such, while the energy used per unit of economic production is consistent with international measures of growth, it does not, however, translate to a proportional increase in country-wide wealth (Sustainable Energy Africa 2014b). South Africa is currently the biggest culprit for GHG emissions in Africa (Odeku 2014; Sustainable Energy Africa 2014b). This has been attributed primarily to the country's almost exclusive dependence on coal for energy, which supplies roughly 93% of the country's electricity (Balmer 2007; Ganda & Ngwakwe 2014; Sebitosi & Pillay 2008; Sustainable Energy Africa 2014b). Building electrification consumes a considerable portion of the national energy supply (Odeku 2014), with the building sector consuming upwards of 40% of this (International Energy Agency 2013). Energy is one of the basic services that South Africans are constitutionally promised (Department of Energy 2012; Sustainable Energy Africa 2014b). For households, energy is essential for services such as cooking, heating (space and water), and lighting. With our growing urbanisation rate, our levels of poverty are also increasing. Urban spatial form plays a vital role in determining cities' energy demand patterns, and the efficient management of resources. The following sub-sections aim to elucidate the energy landscape of South Africa, focusing on conventional, current energy systems, and the future of the resource.

2.7.1 Conventional energy systems for low-cost buildings

Energy is more expensive when you are poor. Relatively speaking, poorer households spend a larger portion of their income on energy costs, compared to their wealthier counterparts. The availability of grid-connected electricity dictates that most low income households use coal as their primary source of domestic energy, because it is economical, reliable and technically efficient, if not environmentally responsible (Balmer 2007; Streeter & de Jongh 2013; Odeku

2014). Houses in townships are often not insulated (Balmer 2007), therefore coal and gas become the fuels of choice due to their dual function: they provide warmth, and facilitate cooking. Energy use patterns are similar throughout low income urban areas in developing countries: cooking, space and water heating is often done with a combination of gas, biomass sources, and electricity, while lighting and the charging of small appliances is done almost exclusively with coal-powered electricity (Streeter & de Jongh 2013). Figure 2.9 shows how energy sources are often distributed within *electrified* low income households in South Africa. For example, 45% of all electrified households use electricity to power their domestic energy needs. As such, energy consumption is dominated by coal-powered electricity (Winkler et al. 2006).

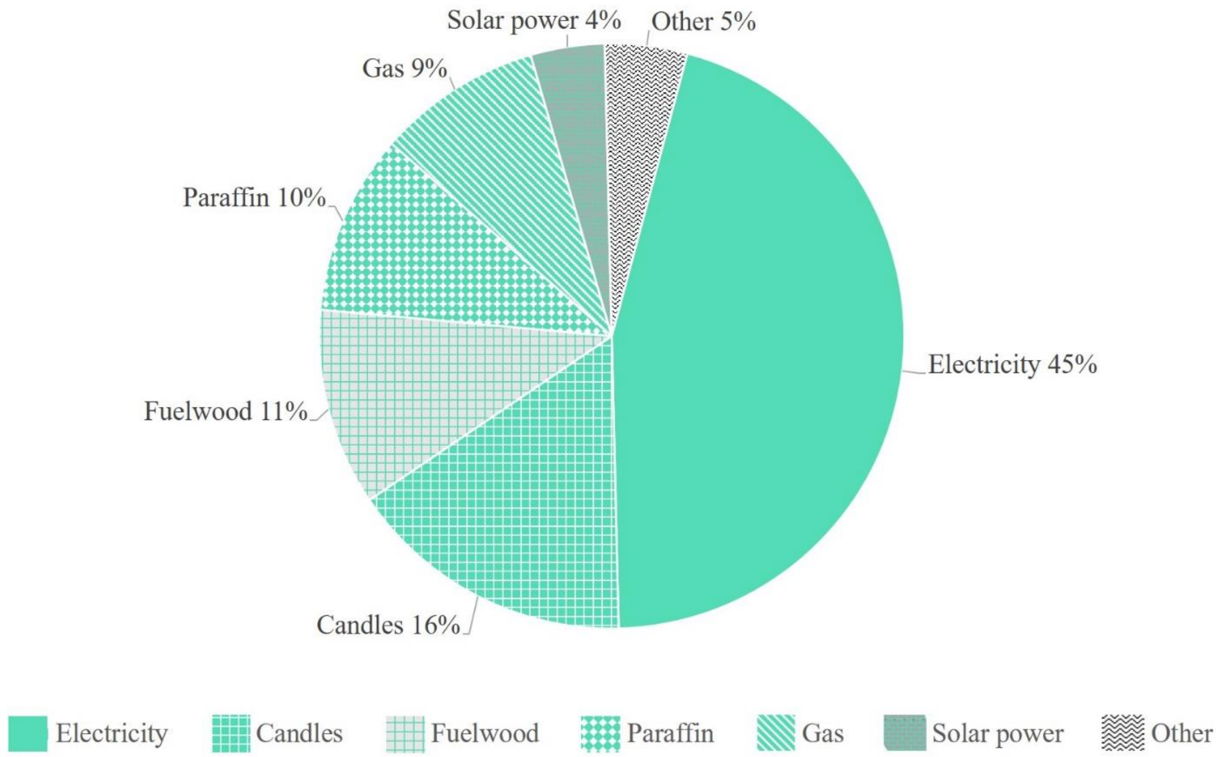


Figure 2.9 Energy Source Distribution in low income electrified households

Adapted from Department of Energy (2013: 20)

It is evident from the information graphically presented in Figure 2.10 that domestic needs of electrified low income households are predominantly met using coal-powered electricity.

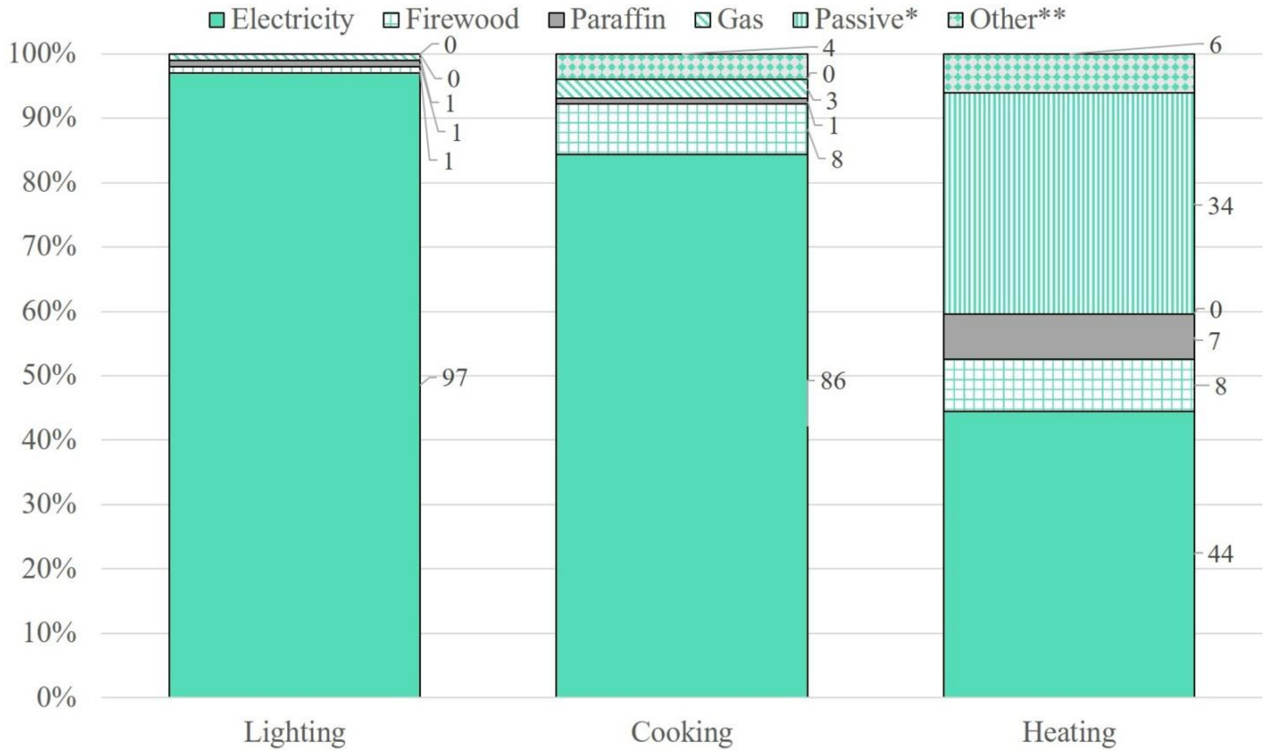


Figure 2.10 Energy consumption source per domestic need of low income electrified households (%)

Adapted from Department of Energy (2012: 23–29)

Due to the irregular nature of their cash flows, and the eligibility factor for free basic electricity programmes (see section 2.8; 2.8.4; and 2.8.7), low income households often buy smaller amounts of pre-paid electricity at a time (Sustainable Energy Africa 2014b). Natural ventilation remains the most commonly found system in place to regulate the heating, cooling and ventilation of low income buildings. However, if designed correctly, this can be sufficiently reliable considering South African climates (Eskom 2016).

2.7.2 Alternative energy systems for low-cost buildings

In South Africa, the government aims to achieve universal access to energy by 2025: to sustainably provide healthy and environmentally friendly energy sources, and electricity (Department of Energy 2012; Sustainable Energy Africa 2014b). This access is informed by its affordability, and the number of households that would connect to these sources (Sustainable Energy Africa 2014b). The need to diversify and intensify national energy supply and to strategize the use of cleaner energy can be seen in the government's electrification agenda (Streeter & de Jongh 2013). Local governments have realised the importance of alternative energy systems as they create sustainable livelihoods within low income communities.

2.7.2.1 Solar water heaters (SWH)

According to many authors (South African Cities Network 2006; Wlokas 2011; Dubbeld 2007), solar water heaters provide a constant, cost-effective supply of heated water, without increasing the pressure on national grids, fossil fuels, or GHG emissions, while at the same time potentially offering job opportunities and reducing energy poverty. This promise may have been why government announced that they would be funding the installation of a million SWHs in South Africa’s low income households by 2014 (South African Cities Network 2006; Wlokas 2011). However, despite this grand announcement, the results are still pending at the time of this study, and no account is kept of the actual number of SWHs installed (South African Cities Network 2006; Wlokas 2011). There are numerous benefits to installing solar water heaters; however, they depend on certain factors. Some of these factors include:

i. Geography and location: In terms of available resources (solar radiation; regional installers; material availability; rainfall area and water restrictions; remoteness affecting regular maintenance and ability to connect to the grid economically).
ii. Cost of technology: the lower the cost, the more likely that it will be adopted. Winkler (2006) is of the opinion that solar water heaters, outside of government or private sponsorship, are not yet affordable to low income communities (Wlokas 2011).

There are many new projects that aim to roll out SWHs on a mass scale in the City of Cape Town, or that roll them out as part of an existing project. Some well-known projects in the City of Cape Town which service low income users include the Kuyasa Clean Development Mechanism Project and the Joe Slovo Projects, which are discussed further in sections 2.9.1 and 2.9.2, respectively. Another commendable initiative by the Western Cape Government is the Solar Water Heater Payback Scheme.

2.7.2.2 Residential Solar Water Heater Accreditation Programme

The City of Cape Town has recently launched this programme to assist with the faster roll-out of residential solar water heaters and to encourage and enable the city’s high energy consumers to decrease their consumption of coal-powered electricity (City of Cape Town 2013; Phakathi 2013). The programme is run in collaboration with city-accredited suppliers and financial institutions to eliminate all perceived obstacles in taking up this agenda. Some of the identified challenges included:

i. High capital cost of alternative energy systems like SWHs, and the installation costs thereof, which have been overcome with the help of credit facilities and financing schemes offered to potential buyers.
ii. The process of installation has been simplified by partnering with twenty local suppliers, who will be held accountable for their services and responsiveness to residents by the City of Cape Town.

In the process, the City of Cape Town has endeavoured to raise awareness on the benefits of switching to solar powered utilities as they have multiple, interconnected benefits to the user, the economy and the environment. While this programme is intended for higher income users, the cost-savings thereof will be of benefit in subsidised efforts to improve the state of energy poverty that low income users find themselves in (City of Cape Town 2013).

2.7.2.3 Rooftop PV

Using the same source of power, namely the sun, rooftop photovoltaic systems have also been adopted by the City of Cape Town in order to alleviate the pressure on the national electricity grid and to facilitate transition towards a 'greener' urban environment. A new strategy recognised as the Energy Security Game Changer, created with the City of Cape Town in collaboration with the Western Cape Government, intends on responding to the current challenges faced in the province by setting some of the following targets in order to reduce the Western Cape's energy demand by 10% in the next three years:

i. A target uptake of 120MW of rooftop PV; and
ii. 400000 SWHs in the residential sector by replacing the existing electric geysers (Western Cape Provincial Government 2016; Didiza et al. 2015).

2.8 Energy efficiency in South Africa

As with renewable systems, energy efficiency is a method of catapulting many a community over the poverty line. Through the acceptance that resources are finite and that they have "limited sink capacities" (du Plessis 2012: 12) for humans to sustain their development, more must be achieved with less. Birkeland (2008) states that, while energy efficiency is a key component of eco-retrofitting, developers actually have little incentive for investing in these energy efficiency systems. This results in limited implementation of these systems. Unfortunately, people are primarily concerned with short-term financial returns. The lengthy payback period and large capital costs often turn many potential investors away, in spite of the minimal operational costs and large savings, both financially and ecologically, on energy consumption in the long run (Birkeland 2008). Ferrao and Fernandez (2013) agree that issues of basic service delivery are of greater concern to the urban poor than those of green retrofits.

The existing South African policy space which attempts to ensure the sustainable transition towards alternative energy for low income groups in townships across the country, is a relatively new one (Brent 2014; Thompson-Smeddle 2012). A number of policies and strategies exist at national, provincial, and district level and many are still under construction. Although energy was not mentioned explicitly in the Constitution of South Africa, it does state that it is the local government's objective to ensure that services are provided to communities in an ecologically sustainable manner (Thompson-Smeddle 2012). Therefore, it is important to recognise that policy alone does not facilitate the necessary transition towards adopting alternative sustainable strategies (Brent 2014). It is through careful implementation and interactive engagement with community that such alternative energy technologies are employed.

2.8.1 National Energy Efficiency Strategy

The National Energy Efficiency Strategy of 2005 proposed to reduce the country's overall primary energy consumption by 12% within ten years – 10% for residential; and 15% for other sectors (Department of Minerals and Energy 2005; City of Cape Town 2014b). In doing so, the strategy strives to reduce the negative impacts of energy use on the health of citizens and on the environment (City of Cape Town 2014b). The National Energy Efficiency Strategy prioritises Energy Efficiency programmes across sectors and categorises photovoltaics and other renewable energy systems as a 'fuel switching' option, especially for low income communities (City of Cape Town 2014b). National Energy Efficiency Strategy is implemented using the Energy Act of 2008, standards (such as the building standards discussed below), certification processes and financial instruments and incentives (De la Rue du Can et al. 2013; Krog 2015).

2.8.2 National Energy Act (Act 34 of 2008)

The objective of this act are to ensure a sustainable and economically viable energy mix; to ensure energy planning and a move towards renewables, contingent supply and energy infrastructure management; to provide measures for energy data; to establish an institution responsible for promotion of efficient generation, consumption and research (Act 34 of 2008; Department of Energy 2013b).

2.8.3 National building standards

The South African National Standards that are issued in terms of the National Building Regulations and Building Standards Act, 1977 (Act no. 103 of 1977) are SANS 204:2011 (SABS 2011a), which enforces energy efficiency in buildings, and SANS 10400 (SABS 2011b) which has two parts: Part X (Environmental sustainability) and Part XA (Energy usage in buildings), which regulates an environmentally responsive and efficient national built environment (Hankinson & Breytenbach 2013; Krog 2015). SANS 204:2011 is not compulsory, but a valuable standard for best practice. SANS 10400-X is not yet completed, however, SANS 10400-XA is mandatory, and enforced by the government with the help of governmental entities, private practitioners, and the Green Building Council of South Africa, in order to steer the transformation of the local building industry towards a greener future.

Employing the guidelines prescribed in the Green Building Council of South Africa's internationally acclaimed rating tools could prove useful in defining a starting point for creating relevant policies in this regard. The law defines the various building types, known as 'occupancies' (SABS 2011b), and states that they must be able to utilise energy efficiency measures, while meeting users' needs in terms of thermal comfort, lighting and hot water, or by having a "building envelope and services" (SABS 2011b) which facilitates a function-appropriate and efficient use of energy that considers the climatic zone within which the building is located. It is said that renewable energy technologies and energy efficiency programs enhance one another: in order to reach international objectives of sustainable energy production and consumption, it is of the utmost importance that they are implemented simultaneously.

The City of Cape Town falls under Climatic Zone 4, which is considered to be 'temperate coastal' (South African Bureau of Standards (SABS) 2011b). This is often used in energy models to calculate the thermal efficiency of the structure based on comparisons of outside and inside air temperatures (for example), in order to determine which energy efficiency measures should be implemented. There are numerous energy efficiency programmes and campaigns underway within the City of Cape Town municipality (Take Charge and Save Campaign; Energy Security Game Changer) as well as a host of policy and strategy documents available on the City's website regarding an energy efficient future Cape Town (City of Cape Town 2015c).

2.8.4 Free Basic Electricity Policy

The Free Basic Electricity Policy was originally developed in 2003 by the South African government, in order to ensure that indigent households could meet their basic energy needs, such as lighting, cooking, and powering smaller appliances (Department of Energy 2013a; Sustainable Energy Africa 2014b). The provision amounted to 50kWh of electricity per residence per month (Department of Energy 2013a; Keller 2012). To be considered indigent, a household must earn a monthly income of less than R2400 (Sustainable Energy Africa 2014b). Even though this policy is in place, not all indigent households receive this benefit (Gaunt et al. 2012; Sustainable Energy Africa 2014b). One of the reasons for this is that Free Basic Electricity only applies to electrified households. In addition, Eskom and municipalities share the responsibility of providing this facility in the bigger cities, and there are often coordination challenges (Keller 2012; Sustainable Energy Africa 2014b). Some municipalities have also adopted a broad based approach, which does not limit the Free Basic Electricity to indigent households alone, but instead to all legally connected households (Sustainable Energy Africa 2014b). In the City of Cape Town, Free Basic Electricity allocation equates to 60 free units for consumption, if a household spends less than 250kWh per month, and 25kWh for consumption if a household spends between 250 and 450kWh per month (Sustainable Energy Africa 2014b; City of Cape Town 2016).

2.8.5 Domestic Tariff

In Cape Town, there are two separate tariffs guided by certain criteria, which determine how much you will be paying for electricity per month (City of Cape Town 2016). The Domestic Tariff is arguably aimed at residential electricity customers of a higher income bracket, as it is only applicable to those who consume above 450kWh on a twelve-month average, each month, including FBE; or anyone who owns a post-paid credit meter, regardless of how many units used per month. This tariff follows a two-block system, where in the first block a user is charged R1,76/kWh up to 600 units, and R2,14 if a user exceeds 600kWh in a calendar month in the second block (City of Cape Town 2016).

2.8.6 Lifeline Tariff

Additionally, the City of Cape Town municipality offers what is known as the 'Lifeline Tariff', a two-block, highly subsidized tariff aimed at existing prepaid electricity consumers who average a monthly consumption profile of less than 450 units, or meet the following criteria:

i. Use an average of less than 450 units of electricity per month over twelve months, AND
ii. Have a prepaid meter; OR / AND
iii. have a municipal property valued at less than R300 000, OR / AND
iv. qualify for an indigent rebate; OR
v. Are a pensioner or disabled person (City of Cape Town 2016).

In the first block, the first 350 units per calendar month, costs R1, 04/kWh. The second block charges an extra R1, 84 for each unit that is spent after 350kWh per calendar month. i.e. R2,84/kWh (City of Cape Town 2016). This is presumably to prevent low income users from purchasing bulk amounts of electricity and using it all at once, and rather encouraging them to use the smaller amounts more efficiently. However, it should be noted that this is not usually the case, and the cost of a commodity being more expensive in bulk versus in smaller amounts, can prove costly to the low income buyer. The following section looks at this in more detail, and examines attempts to establish EE in township architecture based on reviews of sustainable housing projects and related literature.

2.8.7 Free Basic Alternative Energy Policy

In order to close the energy poverty gap between electrified and non-electrified indigent communities , and to recognise the need for free basic *energy* and not just electricity alone, the Free Basic Alternative Energy Policy was introduced (Keller 2012; Department of Energy 2012; Sustainable Energy Africa 2014b). Alternative sources of *safe* energy that are subsidised as part of the policy include:

i. Solar water heaters and solar panels;
ii. Bio-ethanol gel ('fire gel');
iii. Liquefied petroleum gas; and
iv. Paraffin (Keller 2012).

Under this policy, indigent households receive a minimum amount of R55 per month, which is adjusted every year based on inflation (Keller 2012).

One of the concerns of Free Basic Alternative Energy is that indigent recipients are reluctant to use alternative energies, which are seen as second-rate sources of energy when compared to electricity (Sustainable Energy Africa 2014b; Kovacic et al. 2016). This can be attributed to i) a lack of awareness and education amongst the predominantly non-electrified communities to the benefits of alternative technologies (Sustainable Energy Africa 2014b); and ii) the relevant observation that these alternative technologies are only tested on the poor households and therefore not perceived by wealthier groups as sufficient sources of power. The following are two examples of mass rolled out alternative energy models in townships around the City of Cape Town.

Approaches to establish energy efficiency in township architecture

The buildings industry contributes to more than 40% of the world's primary energy consumption, and this is expected to increase by 30% in the next fifteen years (UNEP 2009; International Energy Agency 2013). There are numerous documented approaches to achieving energy efficiency in built environments. Some of them are simple and inexpensive, while others may utilise expensive and complicated technologies. In predominantly low income settlements like townships, it is important that steps taken are cost-effective both in their upfront costs, and in terms of maintenance, to ensure that they remain efficient.

One of the biggest problems with low-income buildings is that they are thermally inefficient (Department of Energy 2012; Sustainable Energy Africa 2014b; City of Cape Town 2015c). This means that these buildings have poor thermal comfort levels due to being badly designed and poorly built, with no ceilings or insulation, which means that they remain cold in the winter months, and are hotter inside than they are outside during the summer months (Tonkin 2008). Thermal comfort is user-dependent: one person may feel hotter than another at any given time due to other factors, such as internal body heat, air temperature, weight, physical activity, radiant temperature (the amount of heat which is radiating off the walls, floors or windows) or clothing (Krog 2015). As such, an acceptable thermal comfort level is determined based on the opinion of all the users (Department of Energy 2012). Thermal inefficiency has a big impact on the energy required to heat buildings, and is an important indicator of energy poverty (Sustainable Energy Africa 2014b).

Simple, sustainable energy efficiency measures, in the form of upgrades, renovations, or factors to be considered during new-builds, which can lead to a better quality of living for low income building users, are listed below. These approaches are based on results from built and lived-in projects such as the ones mentioned below and elsewhere in the world, and categorised according to their level of difficulty to implement (Attia et al. 2012; City of Cape Town 2012; Krog 2015; Sustainable Energy Africa 2014b; City of Cape Town 2015c).

Table 2.2 Energy efficiency measures by level of difficulty

Measure	New build or renovation	Easy	Challenging
Considered orientation of building: commonly used rooms such as living rooms and kitchens to face north; and bathrooms and storage rooms to be placed on the southern façades as far as possible.	New build		
Design windows and doors to allow for cross-ventilation to prevent need for additional heating or cooling devices. i.e. make use of natural ventilation	New build		
	Renovations		
Install shading devices.	New build		
	Renovation		
Optimise window size and position	New build		
	Renovation		
Installation or replacement of energy intensive electric geysers with solar water heaters or heat pumps	New build		
	Renovation		
Installation of Rooftop PV	New build		
	Renovation		
Installing new (insulated) ceilings and insulating existing ceilings	New build		
	Renovation		

Replacing inefficient lighting with efficient lighting. For example, replacing incandescent lights with CFL lights.	New build		
	Renovation		
Building roof overhangs.	New build		
	Renovation		
Adding floor coverings that have thermal properties	New build		
	Renovation		
Install airtight windows and doors which fit their frames or retrofit leaky ones	New build		
	Renovation		
Plaster and paint walls	New build		
	Renovation		
Sufficient plugs and electrical distribution board	New build		
	Renovation		
Paint roofs white or use white materials for roofs	New Build		
	Renovation		

Source: Author

These measures are deemed ‘easy’ or ‘challenging’ based only on the apparent level of skill required to carry out the operations, and have no correlation to financial costs of implementation. The following two projects are examples of initiatives made within Cape Town’s townships. They are unfortunately exceptions to the rule, and not the reality of what all townships around the city are afforded.

2.9.1 Kuyasa CDM Project

In Khayelitsha, a township in the City of Cape Town, projects like Kuyasa Clean Development Mechanism (CDM) show initiative within low income urban communities to address the poorly designed and built Reconstruction And Development Programme houses, and related energy poverty (Wlokas 2011; Donaldson et al. 2013; Streeter & de Jongh 2013). The project, in collaboration with SouthSouthNorth (an NGO) and the City of Cape Town, retrofitted 2300 low-cost houses within the newly formalised Kuyasa settlement in

Khayelitsha, with solar water heaters (pictured below); energy efficient lighting, and installed ceilings to improve insulation (South African Cities Network 2006; Donaldson et al. 2013; Streeter & de Jongh 2013; Krog 2015). Another notable project which incorporated sustainable considerations for optimal energy utilisation was the Joe Slovo housing project in Langa.

Photograph 2.13 Solar Water Heaters in Kuyasa, Khayelitsha

Source: Kretzmann (2009)

2.9.2 Joe Slovo Housing Development

The Joe Slovo project is effectively a sustainable housing delivery project which intends to respond to the failures of the nationwide post-Apartheid Reconstruction And Development Programme (Sustainable Energy Africa 2014a). It is situated in Langa Township, outside the city centre, along the National Highway 2 (N2). The project incorporated various sustainable design elements to counter the inefficiencies of previous council housing developments (Tonkin 2008; Sustainable Energy Africa 2014a; Krog 2015). These included:

i. Insulated ceilings;
ii. Roof overhangs;
iii. North facing buildings where possible;
iv. 150 litre low pressure solar water heaters mounted to face North on 17degree pitch roofs for optimal solar gains;
v. Plastered shared walls;
vi. CFL lights instead of incandescent lights were fitted in all new homes; and

vii. High density development by designing duplexes with shared walls instead of standalone houses.

These small changes go a long way in changing the energy behaviour of residents.

Figure 2.11 Solar water heaters on top of Joe Slovo housing unit roofs

Source: City of Cape Town (2015c)

2.10 Indicators relevant to energy and building performance

Informed by current literature, this section highlights indicators that were deemed relevant for the selection of representative low-cost building in the City of Cape Town.

2.10.1 Relevance of proximity of township to city on selection criteria

The Glossary section of this study defines the term ‘first ring’. Apartheid laws played a pivotal role in the formation of the City of Cape Town, and aided the urban sprawl by pushing people to the city’s ever-expanding edge (Doig 2013). As cities grow, their edges begin to evolve based on their proximity to the city centre (Batty 2008). This growth also signifies a potential bridging in the gap between the city centre and the areas on the periphery, which encourages the physical networks and infrastructure required to conduct resource flows (Batty

2008). These urban settlements provide access to two main factors, namely jobs, and housing. The distance of the township to the city determines this: the closer ones open up job opportunities, while the townships which are less centrally located are geared towards housing (Weakley 2013). Informal settlements are often developed within and around townships which fall within this ring.

2.10.2 Relevance of building age on selection criteria

As explained in sections 1.1 and 2.5.2, Apartheid influenced every aspect of South Africa's development. Therefore, the period during which the buildings were constructed (their age; categorised by their existence before/during, and after Apartheid) becomes important in determining the diversity of the building stock. In numerous building typology studies, building age is important because it provides insight into the type of materials used, and the building standards in place at the time (if at all). This information offers some guarantee for the quality of buildings. In the case of creating typologies based on energy profiles, factors such as thermal insulation, and the approximate energy use, can be surmised from the year of construction (Dascalaki et al. 2011; Filogamo et al. 2014; Aksoezen et al. 2015).

2.10.3 Relevance of race on building stock diversity

South Africa's history of Apartheid played a crucial role in the racial makeup of the urban periphery, as discussed in section 2.5.2. The City of Cape Town only adopted the Group Areas regulation in 1957, transitioning quickly from the least to the most segregated city in the country at the time (Lemon 1991). According to his chapter in The New Blackwell Companion to the City, Seekings (2011) writes that, while White South Africans lived in well-serviced areas with sufficient infrastructure, the Indian and Coloured populations were moved to less established neighbourhoods, with poor infrastructure, and compounding issues of poverty. Even worse, African people were housed in 'townships', with minimal services altogether, as they were not considered to be permanent dwellers (Seekings 2011). Generally, the Coloured neighbourhoods can be distinguished from the Black townships by a considerately large number of Apartheid-era housing blocks, known as tenement buildings, as can be observed in the predominantly Coloured Cape Flats (Ahluwalia & Zegeye 2003). Construction materials and designs, while not vastly different, were sometimes better than those used in building the grim 'dog kennels' set aside for Black townships (Wainwright 2014). Coloured and Indian townships were often closer to the city centre, and were afforded units that could accommodate families, albeit with a little imagination (Jacobs 2010; Ahluwalia & Zegeye 2003).

In what Seekings (2011: 539) and Peberdy (2010: 17) refer to as the 'neo-Apartheid' city, segregation is still prevalent today. In fact, Seekings (2011) argues that the majority of South Africa's population still lives in mono-racial areas, which implies a continuation of the legacy of Apartheid. While the individual's race is not relevant to the diversity of the building stock in this study, the history of the location in terms of its racial privileges during the Apartheid era, and therefore the quality of building construction previously afforded to them, is directly relevant.

2.10.4 Relevance of both private and government-subsidised buildings in township selection criteria

The Glossary section of this study defined the types of buildings which were investigated for the purposes of this study. Townships which consist of both housing developments funded by the government, as well as privately constructed buildings, show a diversity in quality and materials used, as well as building practice. Furthermore, communities that are diverse in that they can afford help, and those that can help themselves, regardless of the informal nature of their settlement, ensure diversity in building stock required for this study.

2.11 Summary

This chapter reviews literature based on the requirements of each of the research objectives. The introductory section on urbanisation describes its origins in Europe and western countries, and then the later manifestation in Africa. Throughout this continent, urbanisation has resulted in the formations of slums and numerous smaller secondary cities with various levels of, but consistently rising, inequality. This increased urbanisation has also increased pressure on the available natural resources.

This laid the foundation for the second section on urban metabolism, which deals with the manner in which cities consume and channel their resources to maintain their growth. As urban metabolism is concerned with cities, sustainability and the built environment are of great importance. The topic has garnered interest across disciplines, from its conception to how it is currently approached. This dialogue is vital for understanding urban metabolism at various levels, in order to challenge societal problems and resource efficiency issues associated with increasing population growth, through effective policy making and design.

The various conceptions of sustainability and the built environment are explored, in order to understand what it might mean for a built environment to *be* sustainable. Maximising economic growth; decreasing resource consumption; maximising utility and reducing environmental impacts are the four main parameters to be considered, within which various criteria conform (GhaffarianHoseini et al. 2013). Similarly, there are four factors which play a definitive role in the manner in which buildings influence the urban matrix within which they are found, and with which they interact: site; technical design; indoor and outdoor environment and operation (Conte & Monno 2012). This section also established that the numerous global and national building rating systems are useful for assessing the overall environmental impacts of buildings; creating awareness and encouraging innovation and action on making the built environment more sustainable amongst practitioners, policymakers and building users. There has also been noted criticisms on i) the focus of building rating systems on solely the building (as opposed to the larger matrix), ii) their focus on environmental conservation only (apparent disregard for societal well-being), and iii) how they actually limit innovation with their frameworks. There is, however, consensus on one aspect of sustainability within the built environments, namely that they need to be resilient and vulnerable to some degree, in order to accommodate diversity in their scales of development. Cost, lack of knowledge and experience in the field of sustainability in architecture, lack of transparency and limited selection of sustainable building materials, and a shortage of willing clientele were found to be barriers to a sustainable built environment (Hankinson & Breytenbach 2013).

Low-cost buildings, especially with regards to housing, were investigated and found to be limited to the urban peripheries, where there was very basic, if any, infrastructure. This position further exacerbates the conditions of the urban poor who populate them. In South Africa, this is even worse due to the country's tormented political history. Addressing the challenges brought about by Apartheid has slowed down the government even more, because of how deeply intertwined the issues are in poor urban areas. The decisively dehumanising urban layouts and buildings continue to be used due to an urbanisation rate which exceeds the possibility for abandoning that which is 'helping' to reduce the country's severe housing backlog, even though this comes at a cost, jeopardising both the resident's emotional and physical well-being. To this end, the state and types of formal buildings in townships in the City of Cape Town was investigated. These buildings were non-residential buildings; government temporary housing; rowhouses; maisonettes; cottages; courts; government Reconstruction And Development Programme houses; migrant labour hostels; private residential houses; '2-storey' buildings; and the informal dwellings (shacks and backyard dwellings) which litter the urban landscape.

The typology section revealed a shortage in literature pertaining to African and South African buildings. Established projects based in Europe and elsewhere provide a wealth of online data regarding residential building typologies across countries. This assists in calculating energy performance to meet their country's climate targets. In South Africa, little has been done in developing datasets on any buildings, let alone buildings in townships. The available literature studied refers to types of buildings which can be built or found on certain geographical zones. The typologies were used to i) determine the risks of building on dolomitic ground in the GCRO, and ii) to determine what types of buildings should be integrated into the District Six Area in Cape Town. Another typology study similar to this one was found. However, the study lacked insight on the resource constraints of the typologies identified, and instead attempted to examine ways of optimising the sustainability through design and continued delivery of houses within informal settlements in Durban.

As a resource, energy is an integral aspect of achieving sustainable development. In Cape Town, the field of energy and sustainable development has been explored and examined. As an energy-intensive country, South Africa relies heavily on conventional energy systems such as grid-connected electricity and gas. The energy source distribution of electrified households revealed that after electricity, candles, fuel wood, paraffin and gas are the most used types of energy sources. No low-income households use mechanical heating and cooling systems, which forces the thermal comfort of the spaces which the residents occupy to rely heavily on the designs of the buildings. Policies such as the Free Basic Electricity Policy assist in ensuring that many of the low income households have access to electricity, along with specialised tariffs directed at these households. Although, there has recently been a concerted effort to move away from coal towards alternative energy system, the process has been long and not everyone is convinced of its efficacy, least of all the poor. In order to meet the aim of diversifying its energy supply, policies such as the Free Basic Alternative Energy Policy formed part of the country’s electrification agenda. As well as this, there has apparently been a mass roll-out of solar water heaters and rooftop PV across the country, although the poster children for this scheme have consistently been the Kuyasa CDM project and Joe Slovo Project in the City of Cape Town. There has since been little government-funded or documented expansion into low income areas.

In order to ensure access to energy for urbanising populations, the South African policy space has offered numerous plans meant to address energy efficiency: the National Energy Efficiency Strategy, National Energy Act (Act 34 of 2008), national building standards such as SANS 10400:X and SANS 10400:XA. Based on the literature, energy efficiency measures which could be useful in addressing the challenges of energy waste in township buildings were also studied.

In order to aid the study’s selection of townships with diverse and representative building stock in terms of energy and building performance, various sources were consulted. These looked into the relevance of the distance of a township from its core city, the age of buildings within these townships; the relevance of race in a post-Apartheid South African township, and the importance of having state-funded and private buildings within townships.

Chapter 3 discusses the research design and methodology for this study and describes how each of the research objectives was addressed.

3 Research Design and Methodology

This chapter introduces the overall research design and methodology of the study. It describes the structured framework and process followed by analysing the particular research methods and data analysis techniques used in order to address the research problem and associated research objectives. The research design incorporates varying but complementary methods and tools.

3.1 Research design

Blaxter, Hughes and Tight (2010) are of the opinion that there are several ways to approach a research study. Sometimes these approaches are exclusive, but often studies will find this limiting, and will need to incorporate more than one way of thinking, as was evident in this study. Figure 3.1 shows the research design for this study. It illustrates the process for addressing the research problem by achieving its related research objectives.

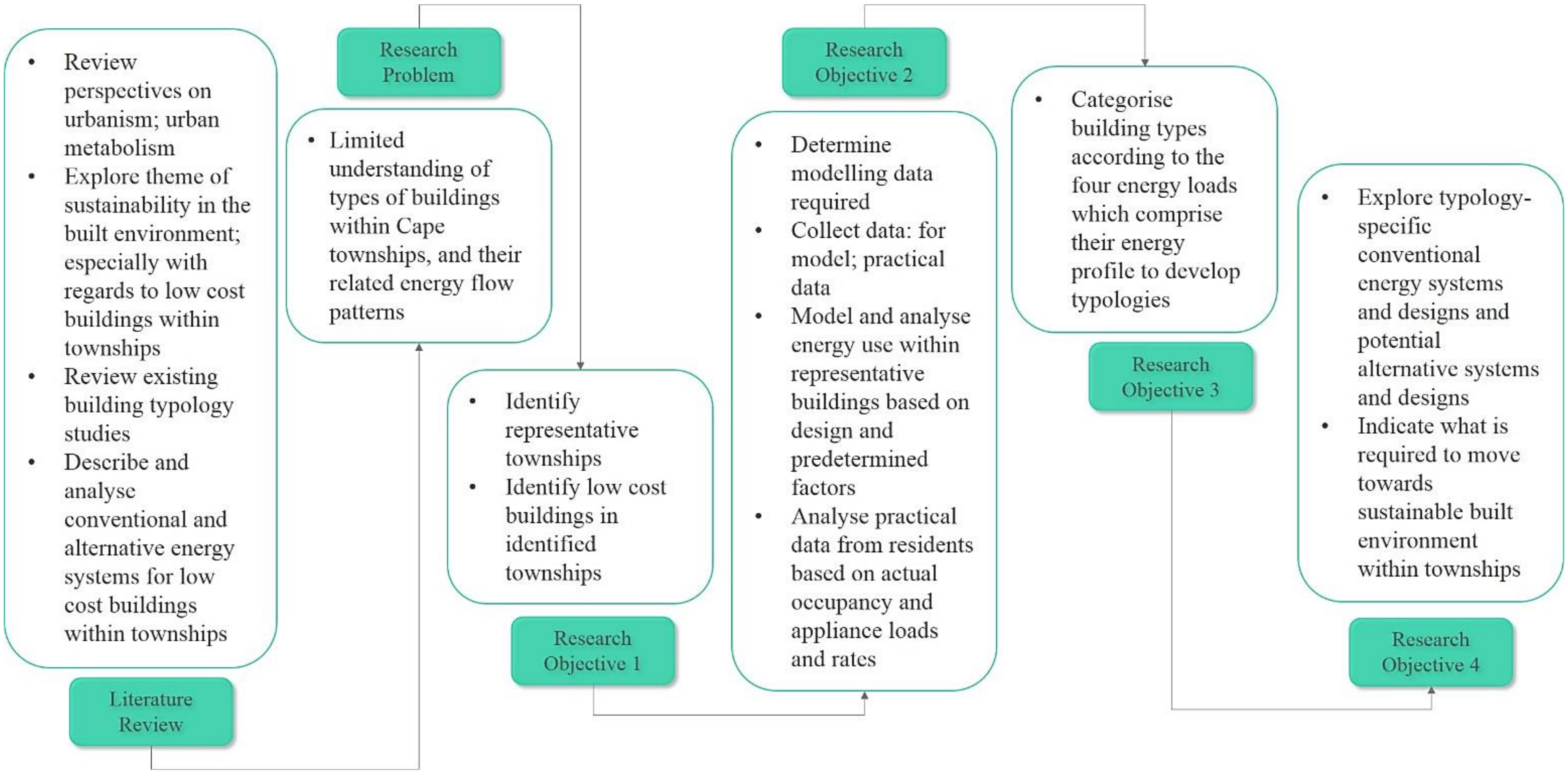


Figure 3.1 Research Design

Source: Author

3.2 Research methodology

Blaxter et al. (2010) makes a distinction between methodology and method. 'Methodology' is seen as a philosophical concept which refers to the underlying approach or intention of the research, whereas the term 'methods' refer to the tools that help achieve this purpose.

Blaxter et al. (2010) identifies two common dichotomies for doing research: quantitative or qualitative, and deskwork or fieldwork. Babbie (1998) further characterises deskwork as that which is related to content analysis and comparative analysis, and fieldwork as that which involves participant or direct observation. Quantitative approaches fall under "the scientific empirical tradition", while qualitative approaches are traditionally more of a "naturalistic phenomenological mode" (Blaxter et al. 2010: 63). This study follows a predominantly quantitative analysis methodology, but also integrated qualitative analyses when appropriate. As an empirical methodology, it employs categorisation methods using existing and estimated data, which refer specifically to classifying the existing buildings by typology. This methodology was used to analyse the energy flows of each representative building within the two case townships of the City of Cape Town. It also includes a qualitative evaluation which establishes the available data and user experience by means of direct observation and semi-structured interviews. Non-empirical methodology is restricted to a literature review which employs existing data on the review of: building typologies, both local and international; energy efficiency policies and energy systems in a South African context.

It could be argued that neither of these dichotomies is real. In fact, many studies incorporate both sets of research strategy, but at varying levels. With regards to the second dichotomy (deskwork versus fieldwork), it is almost impossible to avoid deskwork altogether, especially during the write-up phase. In terms of this dichotomy, this study incorporates both fieldwork and deskwork. Since I live near the identified townships, I took the opportunity to go out to collect research data in the form of photographs, energy consumption information of representative buildings, and interviews with relevant persons. At the same time, deskwork was required in order to review literature, analyse data collected by myself and others, model energy flows of representative buildings, and write. While both fieldwork and deskwork provided ample data to analyse quantitatively, the qualitative aspect of the fieldwork allowed for a better understanding of the deeply rooted issues such as generational poverty, and gang-related violence in both study areas. As indicated, this study was not restricted to one approach, but rather various methods for collecting data were employed in order to gain a more holistic understanding of the problem. The instruments used for this data collection and analysis were objective-specific. This section outlines the applicable research methods, data requirements and criteria, as well as the data analysis techniques for each of the four research objectives.

3.3 Research Objective 1: To classify representative low-cost building types in selected representative townships within the City of Cape Town

The first research objective was to classify the City of Cape Town's low-cost buildings into representative types. In order to do this, it was necessary to first identify representative townships. Thereafter, an appropriate sample size was determined, and from this sample, representative building types were identified.

3.3.1 Identifying representative townships in the City of Cape Town

The City of Cape Town divides its municipal areas into 190 'suburbs'. In order to distinguish which of the 190 suburbs may be categorised as townships, the researcher analysed them in terms of their racial profile and average household incomes (See Appendix A: Suburb Profiles). This was done by making use of data from the 2011 South African National Census (2012). In order to qualify as a township in this study, the suburb had to reflect an average household income level below the poverty line of R3200 per month, and a previously disadvantaged racial composition. This resulted in an initial sample of 46 suburbs that qualified as potential representative townships. Additional criteria were used to choose two representative townships from this sample. As informed by the literature in section 2.10, the total criteria required to be met by the townships in order to produce a diverse and representative building stock was that, (1) the township must be within 20 kilometres of the City of Cape Town Central Business District; (2) the township must have been established before or during Apartheid; (3) the township had to reflect an average household income level below the poverty line of R3200 per month; and (4) the population of the township was mono-racial, that is, either 65% or more Black, or Coloured. The reason for the last criterion is that, although there was initially a preference for a mixed race settlement, the few mixed race settlements that were identified did not meet criteria 1, 2 or 4, and were therefore excluded.

3.3.2 Determining an appropriate sample size

In order to ensure that the sample was representative, multi-stage cluster sampling (Bryman & Bell 2014) was utilised. This entails hierarchical levels or stages of sample-clustering. In the first stage, the suburbs of the City of Cape Town were grouped according to township status. In the second stage, the potential townships for study were determined based on specific selection criteria. In the third stage, two representative townships were identified. In the next stage, the required amount of sample buildings was selected, and in the final stage, the representative buildings within these two townships were selected based on their prominence.

Once two townships were identified, an appropriate sample size of representative low-cost buildings was estimated using Equation 3.1, which is an adaptation of an equation formulated by Krejcie and Morgan (1970). Equation 3.1 was used to find out how many households would be required:

$$\text{Required Sample Size} = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1+\left(\frac{z^2 \times p(1-p)}{e^2 N}\right)} \qquad \text{Equation 3.1}$$

Where *z* is equal to a Z-score of 1.645, a constant which corresponds with the confidence level of 90% (how likely the sample is to be representative of the population);

p is equal to a Standard Deviation of 50% or 0.5;

e is equal to a Margin of Error of 5% or 0.05, which refers to the margin within which the sample is representative; and *N* is equal to the Population Size, which in 2011 was estimated to be 42 411 buildings within the two selected townships (Statistics South Africa 2012).

Once the representative townships were identified, various types of buildings were identified within them. From this, typologies were developed based on the buildings found to be the most prominent or dominant. Building typology was utilised to achieve this objective.

3.3.3 Typology

In this particular study, typology refers to a predetermined classification system in association with a specific category, such as the physical characteristics and related energy profiles of different township buildings. Typologies are useful because they require less time and funding than analysing each individual building (Currie 2015). They can also be used to compare the resource consumption of one type of flow, in this case energy, relative to others. When presented with an initial sample of 46 townships in a municipality, as in City of Cape Town's situation, the benefit of categorizing townships that share consumption behaviours reduces the effort needed to investigate all townships individually.

Content analysis was conducted for numerous building typology related studies, both local and international, in order to understand what constituted a typology, and how to go about developing them. Storie (2011) recognised the differences in low-income settlement types in the Gauteng-City region. Her typologies were useful as a starting point for detailing and classifying the buildings found in this particular region.

In order to classify the current low-cost buildings into their relevant types, it is necessary to directly access the identified sites. The process of categorising buildings in the selected townships, involved the following steps:

(i) Establishing a database for each township, used to input all the collected data.

(ii) Identifying the types of buildings in the representative townships. This was done by capturing photos of buildings while driving through selected townships, as well as talking to residents from each township. The photographs were documented per each township's database, with observed attributes of each building attached to it. These attributes are summarised in Table 3.1 and included: the building's appearance, whether the building was home to single or multiple families, or non-residential; its formality (whether formal or informal structures); building ownership (privately or publicly funded) and building type (e.g. house, apartment, and hostel).

Table 3.1 Township building properties

Data Category		Possible Inputs	Source
1	*Building appearance*	Number of floors; design and materials for roof, external and internal walls, windows and doors	Observation; building drawings
2	*Building type*	Private residential house; government subsidised house – Reconstruction And Development Programme/BNG; NGO affordable housing; rowhouse; informal dwelling/shack; mixed use; Apartheid hostel; apartment/flats; non-residential/public	Observation
3	*Building occupancy*	Single family; Multi-family; Not applicable	Residents
4	*Building formality*	Formal; informal	Observation
5	*Building ownership*	Public; private	Observation; residents

Source: Author

(iii) Identifying the most common formal types of buildings from the photographs captured in step (i). This was done by counting how many times each of the different types of buildings was repeated within each of the databases, which consisted of a sample of 290 buildings in total.

(iv) Selecting the dominant building types to be included in the study. The criteria for selecting the buildings were: (1) accessibility in terms of ground access, that is, on the street; (2) willingness of inhabitants to allow researcher to access the building in order to gather information regarding its energy use; and (3) the building being visible on aerial maps. The nine most common building types, deemed the most dominant, were then analysed further.

(v) Once the building types were identified, a second round of data collection for the selected dominant buildings was undertaken. This included collecting data on: (1) the materials and measurements used for the roof, walls, windows and doors, as well as the construction design thereof, especially with regards to the use of insulation, and orientation of the building; the building's age, gross floor area, and (2) the building's energy profile, which is covered in section 4.3.

(vi) Table 3.2 illustrates how the data for a building typology was captured.

Table 3.2 Building Typology Data

Data Category		Data Sub-category	Possible inputs	Source
1	***General***	*Building size*	GFA (m^2); Floor to floor height (m)	Aerial maps; building drawings
		Age	Years	Observation; residents or building drawings
2	***Design and materials***	*Roof*	Pitch (degrees); cladding; colour; materials	Observation; articles if available
		External walls	Materials; insulation; dimensions (mm)	Observation; articles if available
		Internal walls	Materials; insulation; dimensions (mm)	Observation; articles if available
		Window	Materials; Insulation	Observation; articles if available
		Door	Materials; Dimensions (mm)	Observation; articles if available
		Building Layout	Plans and 3-D models	Observation; photographs
3	***Energy profile***	*Energy System type*	Grid-connected; renewable; Other	Residents
		Average monthly electricity cost	(Rands/month)	Residents
		HVAC System Type	Natural ventilation; hot water heating systems; heaters	Residents

		Average monthly heating/cooling cost	(Rands/month)	Residents

Source: Author

3.4 Research objective 2: To examine energy consumption of the representative low-cost buildings types

The second research objective was to examine the representative types according to their energy consumption. In order to do this, I had to determine what information was required in order to model the energy profiles, or the patterns of energy use, of the buildings. The information was then collected and models run, in order to analyse the energy use within the representative typologies. Practical data, based on actual occupancy, energy use behaviour, appliance loads and rates was also analysed for this purpose.

3.4.1 Data collection

Some of the data required to estimate energy consumption was highlighted in

Table 3.2. This data was obtained through observation, manual evaluation, the use of aerial images, and from the tenants of the buildings. Other data required to fulfil the energy profile modelling process included the occupancy of the buildings, especially the hours the building was used, and how many used the building regularly; the kind of lighting, including the types of fixtures; the hourly weather data which was the same for both townships. This required data was gathered in person, and presented inTable 3.3. In order to evaluate the energy profile of the dominant building types, it was also necessary to ascertain the average energy use per type per month. This was achieved by surveying inhabitants of the representative building types about their energy use behaviour and actual occupancy loads. The different appliances within these buildings were counted and their associated power noted, and the hours for which they were used daily was recorded. Based on this information, their actual annual energy use, and related costs was estimated and cross referenced with the figures derived from the energy models.

Table 3.3 Energy Modelling Data

Data Category		Data Sub-category	Possible inputs	Source
1	*Building Total Occupancy*	-	Number of people/m²	Residents
2	*Building operational hours*	-	Number of hours people are active within the building	Residents
3	*Lighting*	*Types of fixtures*	Incandescent bulbs (watts); CFL (watts), LED (watts)	Residents
		Lighting density	Watts/m²	Residents
4	*Climatic zone*	-	Cape Town's climatic zone and related temperatures and solar radiation (influences hourly weather data)	Online
5	*Hourly weather data*	-	Hourly reference values for 8760 hours (annual) in Cape Town (epw format)	Meteonorm
6	*Energy profile*	*(Equipment internal loads/gains) Types and number of appliances*	Cooking; refrigeration; home maintenance; laundry; entertainment; beauty	Residents
		Power of appliances	Watts/appliance	Residents
		Hours of use of appliances	Hours/day	Residents
		Airtightness	Air changes per hour	Observation

Source: Author

3.4.2 Energy modelling

Energy models were developed to determine the improvements that could be made to the actual building structure and energy systems to ensure more efficient use of energy. In order to run the required energy models, software called DesignBuilder was utilised in conjunction with EnergyPlus, a Building Energy Simulation tool. This software was selected because it is the industry standard simulation engine, and a program that the author is familiar with. In order to run the energy models for the representative buildings, a basic structure which resembled the main features of each building type was drawn up, an example of which can be seen in Figure 3.2. The main features include: correct natural orientation; correct measurements of building block, internal layout and material; correctly sized windows and doors; ceilings, if applicable; correct roof structure, and position in relation to surrounding buildings, if relevant; accurate occupant densities and internal gains, especially equipment and lighting; and a reasonably accurate indication of how *leaky* the building is.

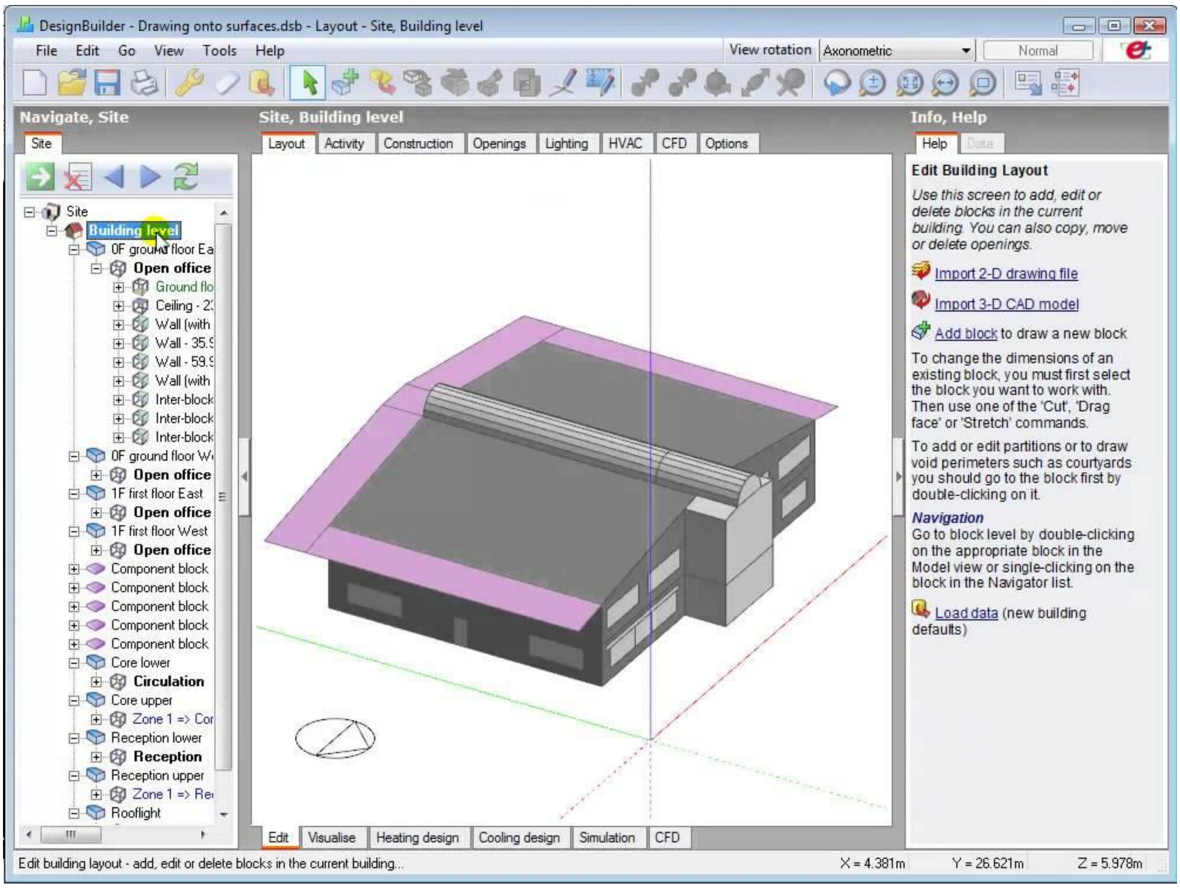


Figure 3.2 Example Designbuilder energy model

Source: Author

Other data which informed the models was recorded earlier in in

Table 3.2, along with data captured in Table 3.3. After setting up the models, the EnergyPlus simulation was run in order to understand the energy consumption of the buildings with regards to their designs and internal heat gains (people; lights and equipment). After the model was run using its current design, three other iterations were run. Table 3.4 indicates which properties were altered per iteration.

The energy charts developed from these simulations were compared to what was known about their average monthly energy use and related costs, with regards to the power of the appliances within the buildings.

Energy profiles are useful because they show where and how much energy is consumed in building. The results produced in this exercise were useful in achieving the third research objective.

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Table 3.4 Model iteration properties

Iteration		Air Changes per Hour	Wall properties	Occupancy rate	Ceiling	Roof properties	Lighting Density	Domestic Hot Water
0	***Current Design***	1	As per design	Current People/m²	As per design	As per design	As per design	Litres per person, using current occupancy rate
1	***Suggested Design***	0,7	Double brick cavity wall, unless otherwise stated	Current People/m²	Yes, standard plaster-board	If asbestos, replace with insulated SANS 10400-XA compliant roof	If currently using incandescent lightbulbs, recalculate after replacing all necessary lights with energy saving lights	Litres per person, using current occupancy rate
2	***Current Design – Sustainable Occupancy***	1	As per design	Suggested* number of people/m²	As per design	As per design	As per design	Litres per person, using suggested occupancy rate
3	***Suggested Design – Sustainable Occupancy***	0,7	Double brick cavity wall, unless otherwise stated	Suggested number of people/m²	Yes, standard plasterboard	If asbestos, replace with insulated SANS 10400-XA compliant roof	If currently using incandescent lightbulbs, recalculate after replacing all necessary lights with energy saving lights	Litres per person, using suggested occupancy rates

Source: Author

3.5 Research Objective 3: To develop typologies of low-cost buildings based on their energy profile

The third research objective was to develop building typologies based on energy profiles. In order to do this, the models from the second objective were used, and information regarding low-cost buildings found in townships from the first objective. The buildings were then categorised according to the four energy loads which comprised their energy profile, to develop township typologies.

3.6 Research Objective 4: To determine the limitations of conventional and alternative energy systems within the low-cost building sector in the City of Cape Town

The last objective was to determine the limitations of conventional and alternative energy systems within the low-cost building sector. In order to achieve this objective, a review was done on both conventional and alternative energy systems currently in use in the City of Cape Town's townships, so as to determine their limitations. Furthermore, which systems were viable per typology, and potential alternative technologies and designs based on the results of research objective two were explored. With this information, recommendations on the requirements for a successful transition towards a sustainable built environment within the township context were discussed.

3.6.1 Direct observation

Through engagement with community representatives and academics from local universities, the researcher was invited into deeper discussions regarding the evolving state of energy within the built environments of Gugulethu and Manenberg. These conversations and personal observations from site visits were recorded in the form of field notes, which were analysed to provide insight into this research objective.

3.6.2 Content analysis

The researcher reviewed numerous peer-reviewed articles on the types of energy systems, both conventional and alternative, commonly found within the two research townships. In addition, published web documents of energy service providers in these areas, and energy efficiency government policies that provided insight into the current state of energy systems and future plans for the areas were investigated.

3.6.2.1 Semi-structured interviews

Semi-structured interviews were conducted with those involved in the niche sector of energy use of low-cost built environment. The interviewees represented a number of different groups:

- Built environment academics and postgraduate students from local universities engaged in relevant research within these locations.
- Residents from the representative townships who inhabit the selected building types.
- Government officials and industry specialists operating sector desks linked to energy efficiency in the built environment.

Snowball sampling resulted across the groups, with each of the interviewees identifying the next person who could add value to the discussion. The township residents were identified by a photo-journalist who has worked in the area for several years. The first point of contact after him was a Community Policing Forum member, who herself is a resident of one of the townships. She introduced me to all the interviewed residents in her township, as well as a contact for another township. The other township's contact introduced me to all the residents interviewed there – nonprobability sampling by way of convenience sampling was utilised by virtue of its accessibility. While the residents identified were approachable and very welcoming, many members of the community were not as receiving. This is discussed in the challenges to sampling section, 4.1.6.1. As a result, it was not possible to run random samples.

Most of the questions asked to the interviewees were open-ended, which allowed for a more holistic understanding of the energy landscape within these townships. Another segment involved a survey of the appliances found in the different homes, as well as the approximate monthly electricity costs. This first style of questioning resulted in responses which could be explored more thoroughly. The second assisted in comparing hard realities with the conceptual energy models to verify their results. During data analysis of the field notes, patterns were identified, providing insights into what is required to make a successful transition towards alternative energy systems and technologies within the township context. This is discussed in the Results and Conclusions and Recommendations sections.

3.7 Summary

Chapter 3 describes the research design and the study's mixed methods approach. Various methods and techniques, such as literature review, typology building and energy modelling, were employed in order to collect and analyse data which was essential for addressing the research problem. Chapter 4 presents the results of the study.

4 Results

In this chapter, the results of this study are presented. The first section offers a visualisation of the most representative townships within the City of Cape Town, from which the two case townships were selected. The second examines the most common types of buildings found within these two townships. The third section analyses the energy use of the representative building types using energy modelling, and the final section offers insights into ways in which these township buildings could become more energy efficient. While the process in accumulating this data was not linear, its presentation thereof is structured in such a way as to convey the information coherently to the reader. This is done by ordering the results according to the research objectives.

4.1 Representative townships in City of Cape Town

In order to classify the City of Cape Town's current low-cost buildings into representative types, the representative townships were first identified, then the low-cost building types within these townships. Of the City of Cape Town's 190 suburbs, 46 were identified as townships that could potentially be utilised for selecting the representative townships. 30 of the 190 urban areas are townships where over 65% of the population is either Black or Coloured, and more than 50% of the population has an average household income less than R3200 per month; 11 of the 46 townships have a similar racial makeup, and more than 40% of the households earn an average monthly income less than R3200 a month. Five of the townships are mixed race (Black and Coloured), with only 50% of the population meeting the poverty line in terms of average household income. This information was gathered from an analysis of Census 2011 data, which was presented in Appendix A: Suburb Profiles, and summarised in Figure 4.1.

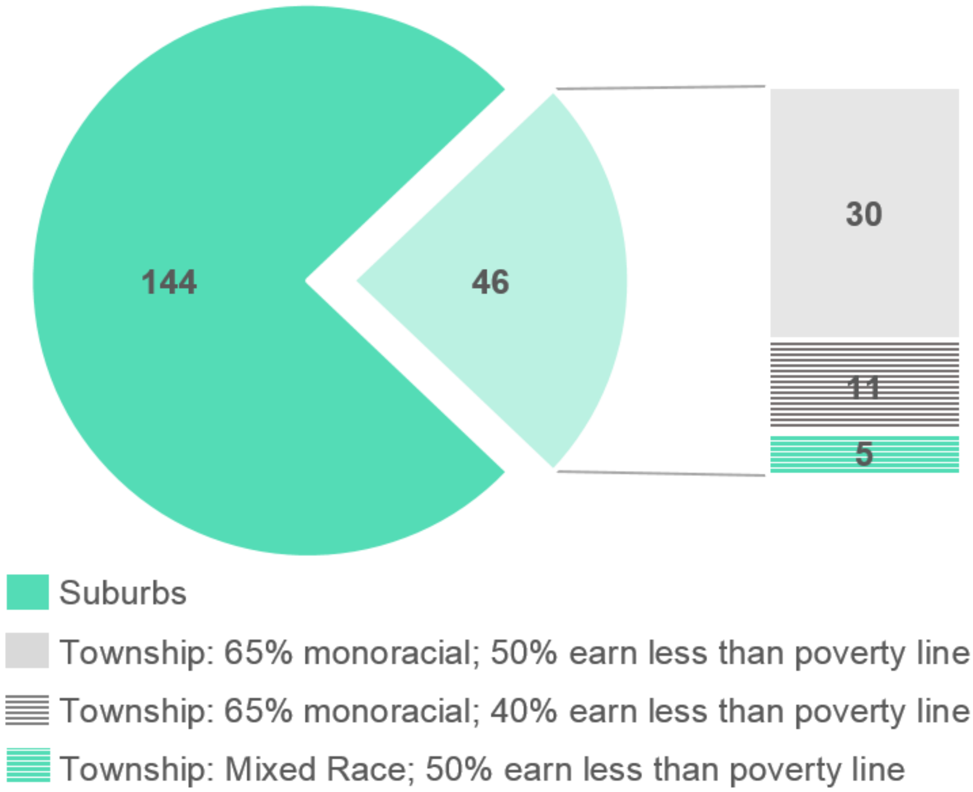

Figure 4.1 Demographic and economic summary of townships in City of Cape Town

Source: Author

Figure 4.2 illustrates the criteria required to ensure that a diverse set of buildings for the typological study was met within this sample of forty six townships. The different colours represent each of the townships, and serve no other purpose. As seen in Figure 4.2, only nine townships met all the criteria. These were Bishop Lavis; Bonteheuwel; Elsies River; Gugulethu; Hanover Park; Heideveld; Manenberg; Parkwood; and Sheraton Park.

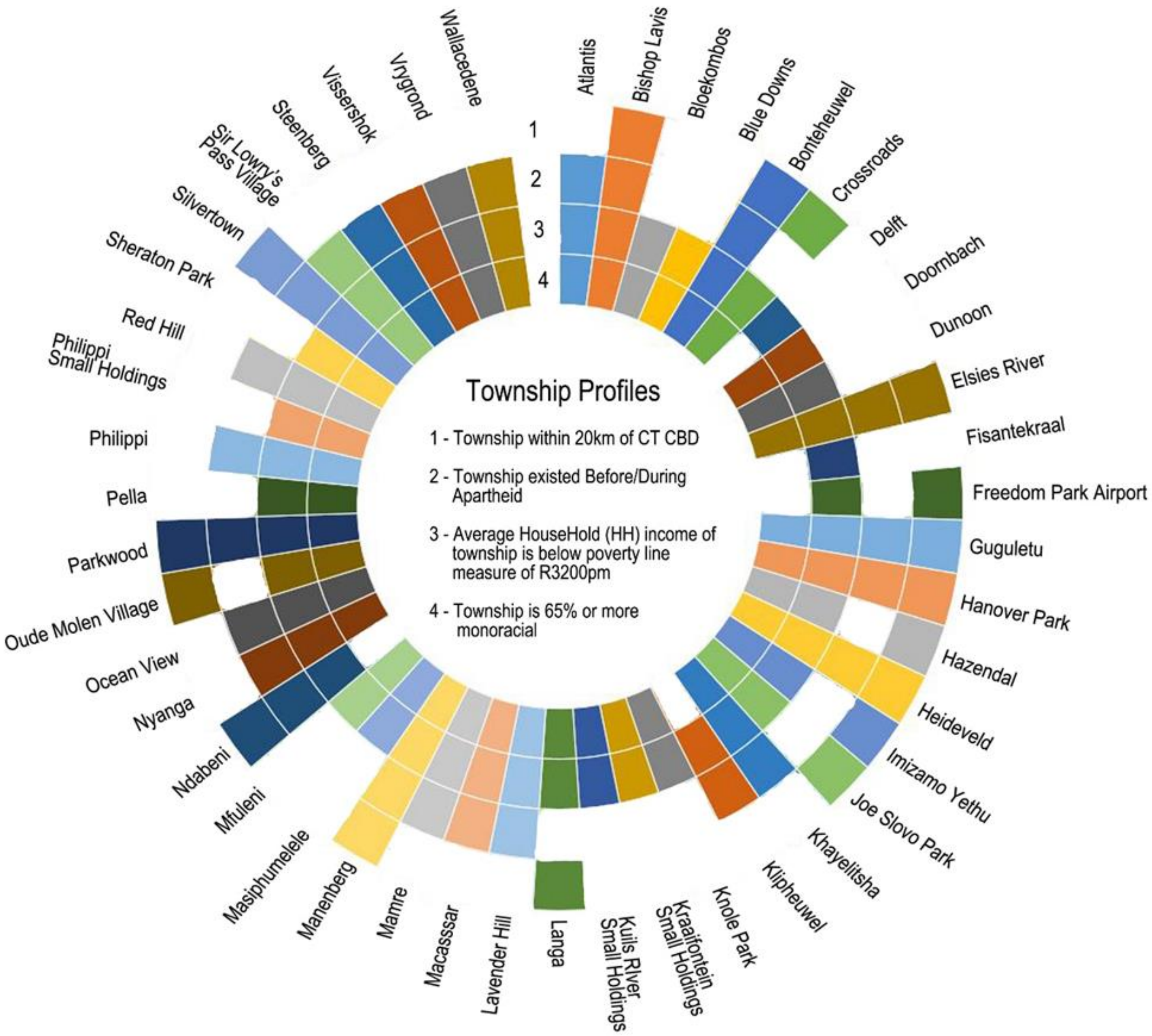

Figure 4.2 Representative sample categorisation

Source: Author

The townships selected were Gugulethu and Manenberg. They were selected because they were the most representative in terms of the four identified criteria, are the most studied, and therefore have the most available data. The required criteria included the following:

- First ring township (closest to the urban periphery)
- Existence before and during Apartheid (building age)
- Mono-racial profile
- Township with both formal (housing development) and informal buildings
- Average household income below the poverty line

The relevance of each of the criteria in ensuring diversity of building stock was investigated in section 2.10, but will be analysed from the perspectives of Gugulethu and Manenberg in the breakdown, following an introduction to the two selected townships.

Gugulethu

Previously known as Nyanga West, Gugulethu, which means ‘our pride’ in isiXhosa, was established in 1958 in the Cape Flats (Teppo & Houssay-holzschuch 2013). IsiXhosa is the language spoken by most of Gugulethu’s residents, who have nicknamed their home ‘*Gugs*’ (Malebo 2016). It was initially created to accommodate migrant workers, other Africans who had been forcefully removed from the City of Cape Town’s centre, and those migrating from the homelands (Teppo & Houssay-holzschuch 2013; South African History Online 2013).

Manenberg

On the other side of the railway line lies Manenberg, a predominantly Coloured township which was developed in 1966 (Jacobs 2010). A member of the Manenberg Community Policing Forum, Roegchanda Pascoe, described how her family has lived in the same flat for four generations – representative of many in her community (Pascoe 2016). Located on the Cape Flats, Manenberg has been described as ‘dysfunctional’ (Jacobs 2010: 13) due to the ghetto-like prominence of gang violence and poverty, an issue which will be discussed in section 4.1.6.1. Manenberg houses Coloured people that were removed from areas that were declared White Areas in the city, like Claremont and District Six (Staniland 2011).

4.1.1 First Ring Township (closest to the urban periphery)

Figure 4.3 illustrates the spatial distributions of urban development as depicted by Geyer et al. (2011). The map has been adapted to include rings that demarcate the 20 km, 30 km and 40 km radii around City of Cape Town central business district. The township highlighted in pink is Manenberg, while the township highlighted in green represents Gugulethu. Both townships fall within the first ring, and are therefore within 20 km of the city centre.

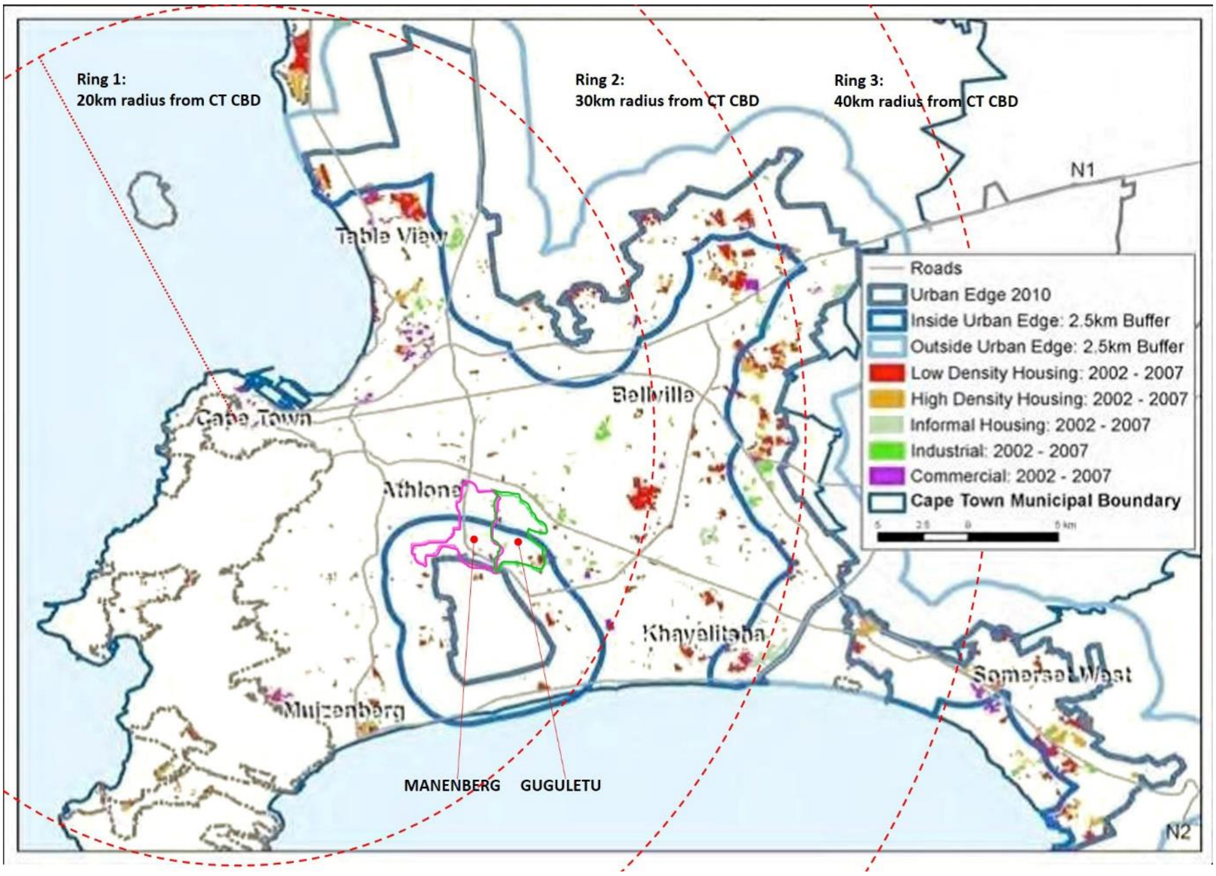

Figure 4.3 Manenberg and Gugulethu - Rings demarcating urban edges in City of Cape Town

Adapted from Geyer et al. (2011: 48)

4.1.2 Existence before and during Apartheid (building age)

As expressed in section 2.10.2, the relevance of townships that were developed before and during Apartheid, is that this has an impact on the diversity of building stock. This diversity can be seen in the townships of Gugulethu and Manenberg (Jacobs 2010). As a system of racial segregation, Apartheid was legislated by the National Party from 1948 until 1994 (Lee 2005; Weakley 2013). One African and one Coloured township were deliberately selected in order to contextualise the various social-political, economic and physical constraints imposed on each of them under Apartheid.

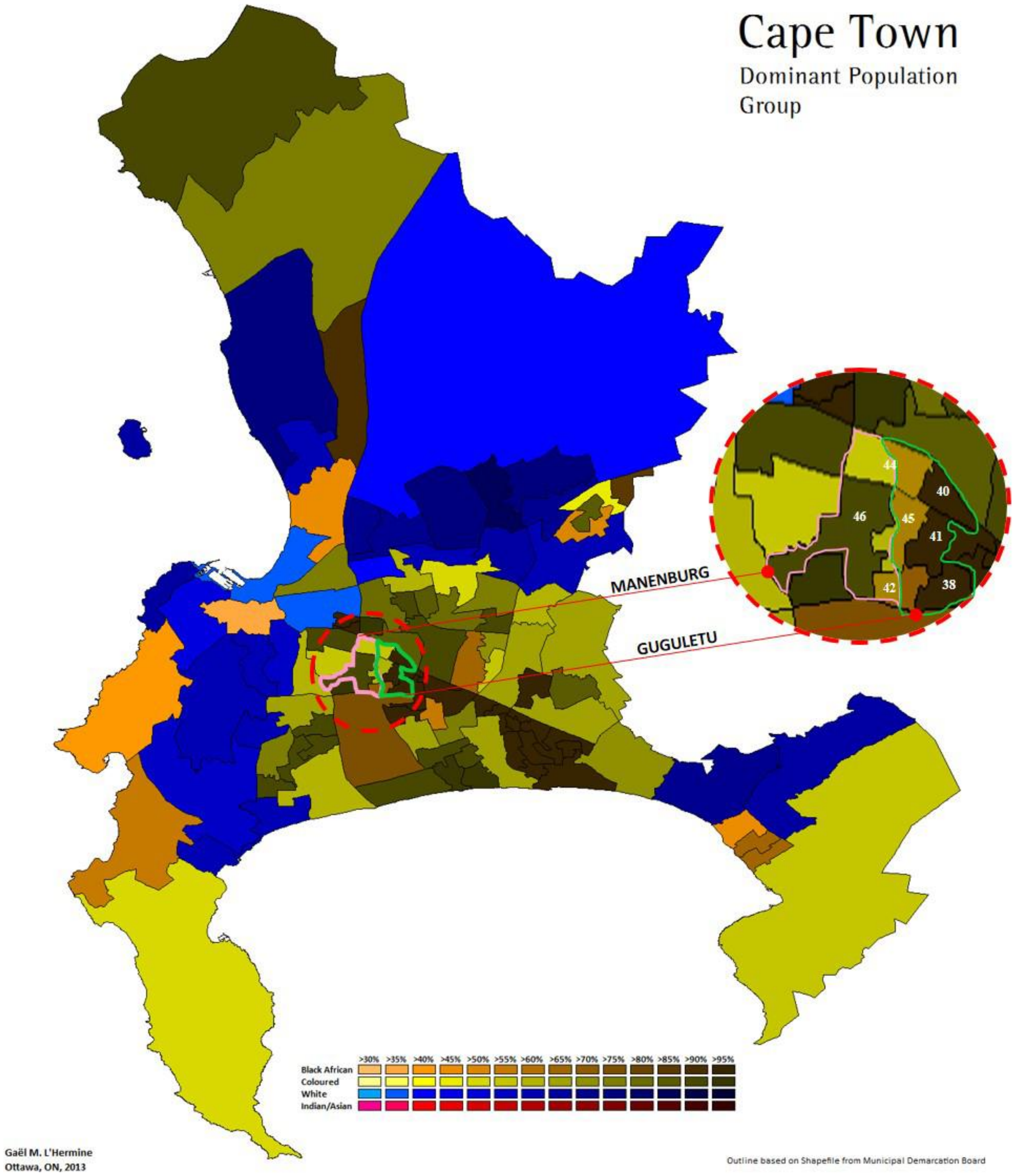

Figure 4.4 Manenberg and Gugulethu - Dominant Population Group

Adapted from L'Hermine (2013)

4.1.3 Mono-racial profile

Figure 4.4 shows the race demographic for the townships of Manenberg and Gugulethu, per ward. The dark brown wards represent the predominantly Black communities of Gugulethu, while the yellow-green wards represent the Coloured communities of Manenberg. The two 'suburbs' are divided by Duinefontein Road which runs parallel to the railway lines (Jacobs 2010). This road, and the racial segregation of these wards, which was as a result of the Group Areas Act described in detail in sections 2.5.2 and 2.10.1, is not indicated in the original image by L'Hermine (2013). It can, however, be seen in the adapted version, where the two townships are highlighted. Referring to the dynamics of the urban system, the South African Cities Network states that "cities are the most productive sites in the national economy as well as the areas that accommodate the largest number of poor people" (South African Cities Network 2006: 2–2). In each of the 46 townships initially analysed in terms of available data, national census statistics revealed that more than 80% of each township's population belongs to a single race – either 'Black' as with the case of Gugulethu, and twenty one others; or 'Coloured' in Manenberg and the remaining twenty three townships (Statistics South Africa 2012). As can be seen in Appendix A: Suburb Profiles, Gugulethu's Black population makes up 99% of the township's total, while Manenberg's Coloured population adds up to 85%.

4.1.4 Townships with both formal (housing development) and informal buildings

All the townships profiled in Appendix A: Suburb Profiles revealed a combination of formality in building types to some extent. Gugulethu was selected as the African township because of its diversity in building types, and its typicality in representing a standard Cape Town African township. It initially consisted primarily of state-owned formal buildings, because the residents were not permitted to own their homes during Apartheid. However, since the political restrictions on home ownership and development were lifted, Gugulethu now displays a collection of newly built private residential houses and public-private amenities such as schools, churches, and shopping centres (Teppo & Houssay-holzschuch 2013). Despite the change in the political landscape, Apartheid-era buildings like the rowhouses and hostel buildings which are discussed in sections 2.5.2.4 and 2.5.2.9, respectively, and the post-Apartheid government-sponsored Reconstruction And Development Programme houses, discussed in section 2.5.2.8, which hoped to combat housing shortages, are abundant on Gugulethu's streets. Shacks and similar informal dwellings, as well as other mixed use non-residential buildings are found in this township, but do not qualify for further analysis.

Manenberg was selected as the Coloured township because of its collection of housing developments and informal buildings, and its resemblance to other Cape Town Coloured townships. Apartheid introduced buildings such as the maisonettes, cottages, courts and '2-

storeys' (discussed in detail in sections 2.5.2.5 to 2.5.2.7, and section 2.5.2.11, respectively) to house the relocated District Six Coloureds. These buildings are still primarily owned by the government, and while serviced – *technically* – leave a lot to be desired in terms of up-keep, maintenance, and historical development. This will be discussed further in section 4.2. Backyard shacks are visible throughout Manenberg, some attached to the serviced formal buildings, some as stand-alone shacks. There are also a number of schools, clinics, and community centres.

4.1.5 Average household (HH) income below the poverty line

All suburbs whose households earned an average income of less than R3200 per month were qualified as townships. The information recorded in Appendix A: Suburb Profiles suggests that both Gugulethu and Manenberg are townships. According to Census data, 71% or more of Gugulethu's households earn less than R3200 per month, and 61% or more of Manenberg's households earn less than R3200 per month.

4.1.6 Sampling Gugulethu and Manenberg

In 2011, there were a combined total of 42 411 buildings in Gugulethu and Manenberg (Statistics South Africa 2012). Equation 4.1 proved that 268 buildings would qualify as a representative sample size.

$$\text{268 buildings} = \frac{\frac{1{,}645^2 \times 0{,}5(1-0{,}5)}{0{,}05^2}}{1+\left(\frac{1{,}645 \times 0{,}5(1-0{,}5)}{0{,}05^2 \times 42411}\right)} \qquad \text{Equation 4.1}$$

Nonprobability sampling through convenience sampling, and snowball sampling methods were utilised. As a dominant method, snowball sampling was apparent in the ways in which contacts were identified for interview and survey purposes. It was not possible to run random samples due to the townships' general negative reception of outside people and groups. This is discussed in the challenges to sampling section, 4.1.6.1. However, based on the information that was relayed to the user by the interviewed residents, as well as information collected from literature, the researcher is of the opinion that the sample is representative, if not random.

Joyce Malebo, a member of Gugulethu's Women's Circle[1], was identified by Roegchanda Pascoe, a member of the Manenberg Community Policing Forum[2], during a site visit to Manenberg. Pascoe was introduced by a photo-journalist, Thomas Holder, who worked extensively in the area until the end of May 2016. Malebo introduced the researcher to several residents in her community who lived in the representative building types found in Gugulethu and similar African townships, such as Langa, Nyanga and Crossroads, amongst others. All of the identified residents interviewed in Gugulethu were women, and Black. In Manenberg, Pascoe introduced the researcher to numerous residents who each warmly welcomed her into their homes. Manenberg residents were also predominantly female; however, there was one male respondent. All Manenberg's residents who were interviewed were Coloured.

4.1.6.1 Challenges to sampling

While the residents identified were approachable and very welcoming, many members of the community were not as receptive. Gang culture and a culture of dismissal and rejection by municipalities and the government has resulted in fear and hesitation towards outsiders within both communities, but especially in Manenberg (Pascoe 2016). On one visit to Manenberg, the researcher was followed by a gang informant before she reached the person with whom she was meeting. The informant was tasked with verifying her identification and level of threat in order to allow her to continue her research in the area. This is not a particularly linear process of evaluation, either. 'The guys', as Pascoe (2016) referred to them, were already on the move, but were put at ease by Pascoe on verification of the researcher's credentials with the informants, and by showing the community that the researcher meant no harm by walking around with her and letting her be seen with Pascoe. Various other informants, some of whom were small children, were similarly tasked and approached Pascoe and the researcher during the visits. Throughout the research period, there were surges in gang-related activity. For a long period last year, the darkness offered by load-shedding prevented Manenberg from being accessed as violence and gangsterism was rife (Holder &

[1] The Women's Circle in Gugulethu is a community-based organisation which empowers women to become active members of their society (The Women's Circle Learning Circles 2015). There are member groups in townships across the Cape Flats, who come together once a month to discuss commonalities, motivation each other, and to advise and learn from each other on how to approach problems that are relevant to their communities (Malebo 2016).

[2] Manenberg Community Policing Forum is a community-based group established by the Manenberg Police Station under section 19 (1) of the South African Police Service Act of 1995, to help build relationships within community, its many sub-organisations, influential parties, and the police. Its main purpose is to 'create and maintain a safe and secure environment for citizens living in the CPF's area' (Western Cape Provincial Government 2014). The MCPF also often acts as a spokesperson for the community(Pascoe 2016).

Koyana 2015). News articles, police reports, and tip-offs from journalists working in the area were used to monitor the situation in order to safely access the sites.

In Gugulethu, while the situation was *seemingly* not as menacing, the researcher dealt with residents of the labour hostels throwing rubbish at her car and showing her obscene gestures during a drive through the area. Admittedly, this was only the researcher's first visit to the hostels, and that too not a pre-organised one – only the photojournalist accompanied her, and not a resident member of the community. On the second and third visits, the researcher was accompanied by Malebo and another resident, and while there was nothing thrown at the car, one man blocked the car on the way out and gestured to the researcher crudely, without letting the car pass. Many other residents stopped the researcher to find out what she was doing in their space, but most were just genuinely interested in the study and the possibilities of what could be done in improving their current condition with the results.

Another challenge was access to historical municipal plans and architectural drawings for buildings in both townships. Although originally selected based on their popularity, and on the assumption that there would be available data on the existing council homes, this was found not to be the case. The officials approached at City of Cape Town's planning and human settlements departments, were not able to provide the researcher with relevant drawings, and according to residents, these plans have not been made available to them on request either(Pascoe 2016; Syce 2016). The limited literature pertaining to the building designs of council homes and other township buildings, and professional opinions on the older buildings, made trying to build accurate energy models challenging. However, direct access to the sites, and the use of aerial maps like Google Earth Pro, helped to ascertain the materials used, dimensions and design utilised.

4.2 Representative low-cost building types within Gugulethu and Manenberg

Section 2.5.2 goes into detail about the design and material properties of commonly referenced township buildings. All the building types mentioned in 2.5.2 can be found to some extent within Gugulethu and Manenberg. Shacks, informal dwellings, non-residential buildings and private residential buildings are abundant in all townships, but they fall beyond the scope of this study because they cannot be categorised due to their diversity in form and materials, amongst other variant factors. Therefore, only the following nine were analysed:

i. Rowhouses (RH)
ii. Maisonettes (M)
iii. Cottages (Cot)
iv. Courts (Court)
v. Government Reconstruction And Development Programme houses
vi. Migrant labour hostels – 1 storey (MLH1)
vii. Migrant labour hostels – 2 storey (MLH2)
viii. '2-storeys' (2Stor)

The various categories of building properties documented in Table 3.1 were used as a guideline in order to gather the relevant information about the selected township buildings. The following sub-sections provide an overview of this information per building type, which was sourced from a combination of interviews with residents, aerial photographs, literature, and direct observation.

4.2.1 Rowhouse building properties

The following section explores the reality of rowhouse building residents based on observation, and/or personal interviews with residents – depending on accessibility. Photograph 4.1 depicts the front of a rowhouse, which is usually connected on both sides with a number of similar houses. One of the rowhouses visited was at 121 NY89, Gugulethu. The street name, 'NY' 89 translates to 'Native Yard' 89, and is still used in maps today. Gugulethu is filled with streets named this way. In fact, only the main roads are named differently.

The rowhouse buildings were discussed in more detail in section 2.5.2.4. The buildings, colloquially referred to as 'garages' (Malebo 2016; Mdayi 2016), were found to house more than one family. As is common in these low income communities, grandparents, their children, and their grandchildren, along with extended family, typically occupy each *matchbox*. To this day, a majority of buildings still sport asbestos on their roofs. The houses are connected in long rows, across grids throughout predominantly African townships, like Gugulethu, but also some Coloured townships. All the buildings use grid-connected electricity to some extent, relying also on gas for cooking, and paraffin for space-heating. An average of three litres of paraffin is bought each day in the winter months in an attempt to attempt to heat up the cold rooms.

Photograph 4.1 Neighbours sitting in front of rowhouse, 121 NY89

Source: Author

Natural ventilation is the only type of Heating Ventilation Air Conditioning (HVAC) system, because households cannot afford to install any other systems. Despite, or perhaps *due to*, basic architectural education teaching that buildings in the southern hemisphere should optimally face north, the rowhouses predominantly follow an east-west axis in terms of window positions, which makes them very cold, and harder to heat up due to mostly receiving harsh western light and morning light for a short time. They are usually connected on their north and south façades by neighbouring rowhouses. There is not much of a roof overhang or additional shading devices, which adds to residents having to make more effort to cool their homes in summer months, and heat them in winter.

Table 4.1 Rowhouse building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladding*	*Colour*	*Ceiling*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Insulation*	*Materials*	*Dimensions (mm)*	*Materials*	*Dimensions (mm)*
Multi-family	11 degrees	Asbestos	Grey	No	Brick	220	Na	Brick	110	Na	Single glazed window	Na	Wood	25 x 2041 x 832	Concrete slab with linoleum tiles	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m^2)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m^2)**	**Lighting power density (W/m^2)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
38	2,4	40	Grid-connected electricity	0,37	7,9	600	Natural ventilation

Source: Author

4.2.2 Maisonette building properties

The maisonette units were awarded to slightly better off families when they were first developed, and as with most buildings in Manenberg, have remained within the original families over the generations (Jacobs 2010; Pascoe 2016; Smith 2016). The maisonette buildings consist of two units each. It was pointed out that extra space was often given to only the one unit of the duplex, while the neighbouring unit was closed off at the wall. This caused tensions amongst neighbours, and residents argue that this was a part of the design, in order to create animosity amongst people within communities during the Apartheid era (Pascoe 2016; Smith 2016; Syce 2016).

Each unit is double-storey, connected by a corner staircase on the inside of the building, which takes up space valuable space. The buildings are connected to the national electricity grid, and make use of natural ventilation (essentially, opening windows and doors when it gets too hot and closing them when it becomes cold). Regardless of this, however, their location in Manenberg, and similarly impoverished and violent communities, lends to windows that are often cracked and broken. The occupancy rate is better than many buildings in the area, and indicates that on average, seven people live in each three bedroomed unit (Smith 2016). The heights of these units per floor are higher than some of the other buildings. This increased volume often has a negative impact on heating and cooling requirements, which will be discussed further in section 4.5.1. The maisonettes were built with ceilings, even though they were topped off with the now-illegal asbestos sheeting. The construction of the walls is unique: they have a base construction of slightly larger sand brick blocks, and face-brick cladding on the exterior. The walls are not plastered on the interior, but the additional cladding should have an impact on the internal temperatures experienced.

Table 4.2 Maisonette building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladding*	*Colour*	*Ceiling*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Insulation*	*Materials*	*Dimensions (mm)*	*Materials*	*Dimensions (mm)*
Multi-family	11 degrees	Asbestos	Grey	Yes	Sandblock with brick cladding	310	NA	Brick	110	Na	Single glazed window	NA	Wood	25 x 2041 x 832	Concrete slab with linoleum tiles	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m²)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m²)**	**Lighting power density (W/m²)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
32	3,135	55	Grid-connected electricity	0,22	11,67	1200	Natural ventilation

Source: Author

4.2.3 Cottage building properties

According to an interview with Pascoe (2016) and other Manenberg residents (Michaels 2016; Smith 2016; Syce 2016), these are the buildings they would have selected to occupy, had they been given a choice.

The cottages are situated centrally around large yards, with more rooms than the other buildings, despite only having a single level. They are similar to the rowhouses, except that there are only ever two units connected to one another, separated by a thin internal wall. Each unit has an occupancy rate of approximately nine people per house. The house is actually much smaller in size than some other units, however, its popularity seems to come from the illusion of space provided by the extra room division, and the yard on which it sits. Material-use is unoriginal, but these roofs provide a slight overhang. There is no ceiling, and the roofs are made from asbestos.

Table 4.3 Cottage building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladd-ing*	*Colour*	*Ceil-ing*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Mater-ials*	*Dimen-sions (mm)*
Multi-family	11 degrees	Asbes-tos	Grey	NA	Brick	220	NA	Brick	110	NA	Single glazed window	NA	Wood	25 x 2041 x 832	Concrete slab with linoleum tiles	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m^2)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m^2)**	**Lighting power density (W/m^2)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
23	2,4	45	Grid-connected electricity	0,39	3,13	650	Natural ventilation

Source: Author

4.2.4 Courts building properties

The Courts are synonymous with the identity of the gang-dominated heart of the Cape Flats. They are often under fire, and recent internal upgrades afforded to them by the municipality were withheld due to the refusal of the gangs to allow contract workers to renovate. Once residents had moved to temporary housing, their homes in the Courts were vandalised and looted by armed gang members (City of Cape Town 2015b). Eventually, the upgrades were done, but not to the residents' satisfaction.

The courts are characterised by their three storeys and fenced courtyards, with washing lines strung between buildings. Each compound consists of two identical, mirrored buildings, with entrances facing one another, that are spaced approximately five metres apart. The buildings themselves consist of eighteen units across three floors, and are about 45 metres long. They are made of brick are and unplastered, with no ceilings or insulation. The units are very overcrowded, with residents reportedly living with up to 20 people per two bedroom flat. The flats have 'hospital floors' as the residents refer to the linoleum covered concrete. The upgrades to the flats included *new* linoleum floors, door handles and window stoppers which have already broken or fallen off, and internal burglar bars. Electrical wiring and the fitting of a 100-litre capacity hot water urn, as well as a coat of paint, finished the upgrade.

Photograph 4.2 Inside the compound, Madge Court

Source: Author

Table 4.4 Courts building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladd-ing*	*Colour*	*Ceil-ing*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Mater-ials*	*Dimen-sions (mm)*
Multi-family	11 degrees	Asbes-tos	Red	NA	Brick	220	NA	Brick	110	NA	Single glazed window	NA	Wood	25 x 2041 x 832	Concrete slab with linoleum tiles	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m^2)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m^2)**	**Lighting power density (W/m^2)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
36	2,4	50	Grid-connected electricity	0,58	1,67	-	Natural ventilation

Source: Author

4.2.5 Government Reconstruction and Development Programme house building properties

The Reconstruction and Development Programme (RDP) was initiated by the African National Congress (ANC) in order to provide free basic housing to low-income citizens (Goven et al. 2012). The initial buildings were created merely to serve the purpose of shelter, without considerations for any of the interlinked issues of poverty and historically inept spatial configurations imposed on the people they hoped to serve. To remedy this, a newer strategy was introduced, known as the Breaking New Ground (BNG) strategy. However, the buildings constructed under this new strategy did not show much of an improvement. The townships consist of a variety of state-funded buildings, of which the post-Apartheid RDP houses make up a considerable portion. The BNG units, which are not easy to differentiate from their predecessors, save for their year of construction, are also evident on these urban peripheries.

Photograph 4.3 Reconstruction and Development Programme houses, Gonubie Road, Manenberg

Source: Author

The modelled Reconstruction and Development Programme house is one which shares a wall with another unit. They are more or less the same size as the original standalone houses, pictured in Photograph 4.3, but use less material because of the shared wall. There are many types of Reconstruction and Development Programme houses in Manenberg and Gugulethu, but they are all approximately the same size and utilise the same building materials and similar designs. As these buildings were constructed after 1994, roofs are constructed using corrugated sheets instead of asbestos. Despite the insufferable conditions experienced in old Council homes, funding was still not allocated for energy efficient interventions in Reconstruction and Development Programme houses, until recently. Therefore, most of the Reconstruction and Development Programme houses recorded did not include a ceiling, or insulation.

Table 4.5 Government Reconstruction and Development Programme house building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladding*	*Colour*	*Ceiling*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Insulation*	*Materials*	*Dimensions (mm)*	*Materials*	*Dimensions (mm)*
Multi-family	10 degrees	Corrugated iron	Red	NA	Brick	220	NA	Brick	110	NA	Single glazed window	NA	Wood	25 x 2041 x 832	Concrete slab with linoleum tiles	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m^2)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m^2)**	**Lighting power density (W/m^2)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
36	2,4	10	Grid-connected electricity	0,21	1,33	-	Natural ventilation

Source: Author

4.2.6 Migrant labour hostel (1-storey) building properties

One of the woman tenants in Gugulethu invited me into her room. She explained that she has been living in this same room for 33 years. Her brother moved to Cape Town in hopes of finding work, and she joined him (at first, illegally). Once the pass laws were repealed, and Apartheid was abolished, her brother moved back to Queenstown, while she remained.

The tenant currently lives in one room with one of her children, their partner and her two grandchildren. Her other children, who used to live in the hostel unit with her, were relocated to a R5000 shack which was built outside of the hostel – a common occurrence, according to the tenant. As discussed in section 2.5.2.9, there are six bedholds in each *door* of single-storey *Kwakiki* hostels, and four units per long hostel building. Considered to be typical within the hostels, her unit recorded eighteen adults and thirteen small children as co-residents. Lack of privacy remains one of the most common complaints amongst residents: each unit shares one toilet, urinal and shower, and a communal kitchen area with a small sink. The hostels are very cold, with thin, unplastered walls, and no insulation or ceilings. The floors are drab with plain rubber tiles. This, however, is said not to be the norm – apparently many of the hostel dwellers tried to liven up their space by opting for brightly coloured rubber tiles for floor covering. Her unit, however, barely has any covering in addition to the cold, stark, concrete floor slab. Each bedhold (room) is home to an average of six people, which makes the rooms quite stuffy. The photograph of the tenant’s room below shows how she has made optimal use of the limited space. In her case, she has her own appliances inside the room. She complains of the walls being too thin, and of having to ask her neighbours to use their toilets as the hostel’s single toilet frequently gets blocked due to the high occupancy rate of the flat.

Photograph 4.4 Inside a Migrant Labour Hostel Bedhold

Source: Author

Table 4.6 Migrant labour hostel (1-storey) building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladding*	*Colour*	*Ceiling*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Dimensions (mm)*	*Insulation*	*Materials*	*Insulation*	*Materials*	*Dimensions (mm)*	*Materials*	*Dimensions (mm)*
Multi-family	11 degrees	Asbestos	Grey	NA	Brick	220	NA	Brick	110	NA	Single glazed window	NA	Wood	25 x 2041 x 832	Concrete slab with rubber tiles	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m²)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m²)**	**Lighting power density (W/m²)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
288	2,42	40	Grid-connected electricity	0,625	5	R 600	Natural ventilation

Source: Author

4.2.7 Migrant labour hostel (2-storey) building properties

The Hostels Transformation Project is finally under way in Gugulethu, in an effort to address the "extreme overcrowding and dilapidated state of the hostels" due to Apartheid and the city's migrant labour system (City of Cape Town 2014a). It has not yet been decided whether the hostels will be altered to accommodate family living, or if new buildings will be built.

The two-storey hostels are accessed by a set of external stairs which link to a narrow balcony strip. The layouts of the *doors* remain the same as with the single storey hostels, however the building materials are a bit different. Instead of brick, the two-storey hostels employ a sand brick block which is not plastered, but painted. It sports red roofs with no ceilings, or insulation.

Table 4.7 Migrant labour hostel (2-storey) building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladd-ing*	*Colour*	*Ceil-ing*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Mater-ials*	*Dimen-sions (mm)*
Multi-family	12 degrees	Asbes-tos	Red	NA	Sand brick block	200	NA	Brick	110	NA	Single glazed window	NA	Wood	25 x 2041 x 832	Concrete slab with rubber	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m²)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m²)**	**Lighting power density (W/m²)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
198	2,8	40	Grid-connected electricity	0,44	3,7	-	Natural ventilation

Source: Author

4.2.8 '2-storey' building properties

Of all the building types explored in Manenberg, the '2-storeys' were the most dilapidated and cramped. They are severely overcrowded and completely ignored by the municipalities. Any endeavour to make the space more liveable has been by the residents themselves, and often with illegal extensions or backyard shacks. The top floor flats are considerably better than the smaller flats below – the top floor is divided into two flats, while the bottom floor is commonly divided into three flats. In terms of home improvement, the changes were slow but incremental: as cash flow was available, small alterations were done. Surprisingly, most of the 2-storeys residents made use of energy saving lights already, unlike many of the other buildings' residents. The windows and doors hardly ever fit properly into their frames (usually because the frames were an afterthought by the council, and only added on later), which resulted in a lot of air leakage.

The 2-storeys have linoleum floors, grey asbestos roofs and a very high occupancy rate. The rooms are very dark because of the poor choice in orientation, and warm due to the congested space, even though it was very cold outside. This will be examined further in section 4.3.

Table 4.8 '2-storey' building properties

Family Type	**Design and Materials**															
	Roof				**External walls**			**Internal walls**			**Window**		**Door**		**Floor**	
	Pitch	*Cladd-ing*	*Colour*	*Ceil-ing*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Insula-tion*	*Mater-ials*	*Insula-tion*	*Mater-ials*	*Dimen-sions (mm)*	*Mater-ials*	*Dimen-sions (mm)*
Multi-family	11 degrees	Asbes-tos	Grey	NA	Brick	220	NA	Brick	110	NA	Single glazed window	NA	Wood	25 x 2041 x 832	Concrete slab with linoleum tiles	75 + 10

Building size		**Age**	**Energy profile**				
GFA (m²)	***Floor to floor height (m)***	**(y)**	**Energy System Type**	**Occupancy (people/m²)**	**Lighting power density (W/m²)**	**Average monthly electricity cost (R/month)**	**HVAC System Type**
90	2,4	50	Grid-connected electricity	0,54	3,75	600	Natural ventilation

Source: Author

4.3 Energy consumption of representative low-cost building types in Gugulethu and Manenberg

The second objective was to examine the energy consumption of low-cost building representative types.

The energy consumption rates of township buildings was determined by finding out the energy uses per type using energy modelling, and through measuring the energy use from appliances and lights in the buildings. In order to examine where the building was using the most energy, it was important to create various scenarios for simulation. Four iterations were made, with minor changes per type, considering design, lighting loads, and occupancy loads, which affected the energy used for domestic hot water, being targeted. Equipment loads were disregarded because the loads are not as high as in higher income groups or non- residential building uses. It is also not likely that they will be improved before more economical options become available. In addition, the current equipment loads to do not contribute much to the heating of the spaces, as can be seen in the results from the thermal gains graphs in section 4.5.1. The four iterations were as follows, with potential changes documented in Table 4.9 implemented per iteration.

Table 4.9 Energy model iterations

Iteration		ACH*	Walls	Occupancy**	Ceilings	Roof	Lighting***
1	Current Design (CD)	As per design	As per design	As per design	As per design	As per design	As per design
2	Suggested Design – CD occupancy; material changes; not leaky	0,7	SANS 10400:XA approved	As per design	SANS 10400: XA approved	SANS 10400: XA approved	Improved to a density of 1x 12W CFL per room)

3	**Current Design – Sustainable Occupancy**	As per design	As per design	Improved to a density of between 0,1 and 0,25	As per design	As per design	As per design
4	**Suggested Design – Sustainable Occupancy**	0,7	SANS 10400:XA approved	Improved to a density of between 0,1 and 0,25	SANS 10400: XA approved	SANS 10400: XA approved	Improved to a density of 1x 12W CFL per room)

Source: Author

*ACH stands for Air Changes per Hour, which refers to how airtight a building is (usually related to windows and other openings). 1 ACH means that the entire volume of air in the building is replaced in one hour. The more airtight a building is, the less this number becomes. A standard improved ACH of 0,7 is used for all the suggested design iterations.

**Occupancy refers to the number of people who occupy the building, per square metre. This rate often has a big influence on the heating and cooling requirements of a space, and is therefore very important to include, especially in oft-over crowded buildings like those in the townships. Occupancy loads also have a direct impact on the amount of domestic hot water which is generated.

***Lighting (density) refers to the number of watts per square metre. Many residents in townships still use inefficient incandescent lights because they are cheaper. This increases their lighting consumption, and related costs. In buildings where the lighting density is high due to these types of lights, they are replaced with one 12W CFL light per square metre.

Another relevant input in all the models was the MeteoNorm weather data for Cape Town weather station closest to the airport, and the input of location under Climatic Zone 4 (under which Cape Town falls due to its coastal temperate climate).

4.3.1 Rowhouse energy consumption

The information documented in 4.2.1 was used to generate a simple model on DesignBuilder.

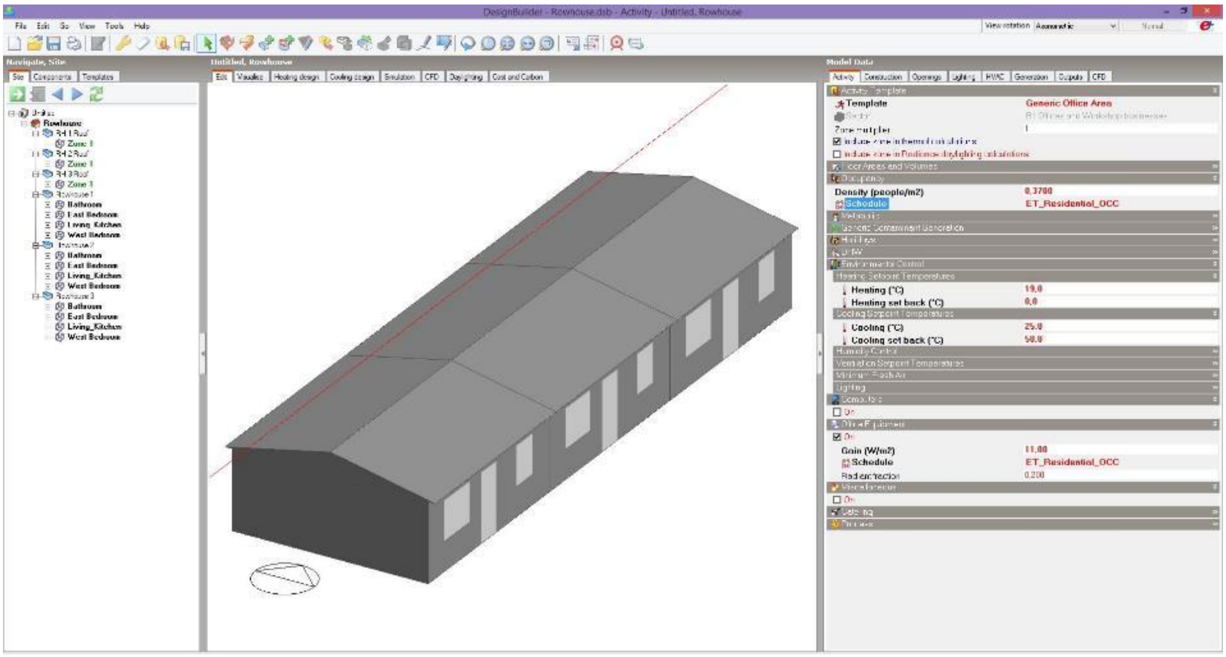

Figure 4.5 Rowhouse - DesignBuilder model

Source: Author

This rowhouse was modelled with only three units, and is positioned typically in a north-south axis with east and west facing windows.

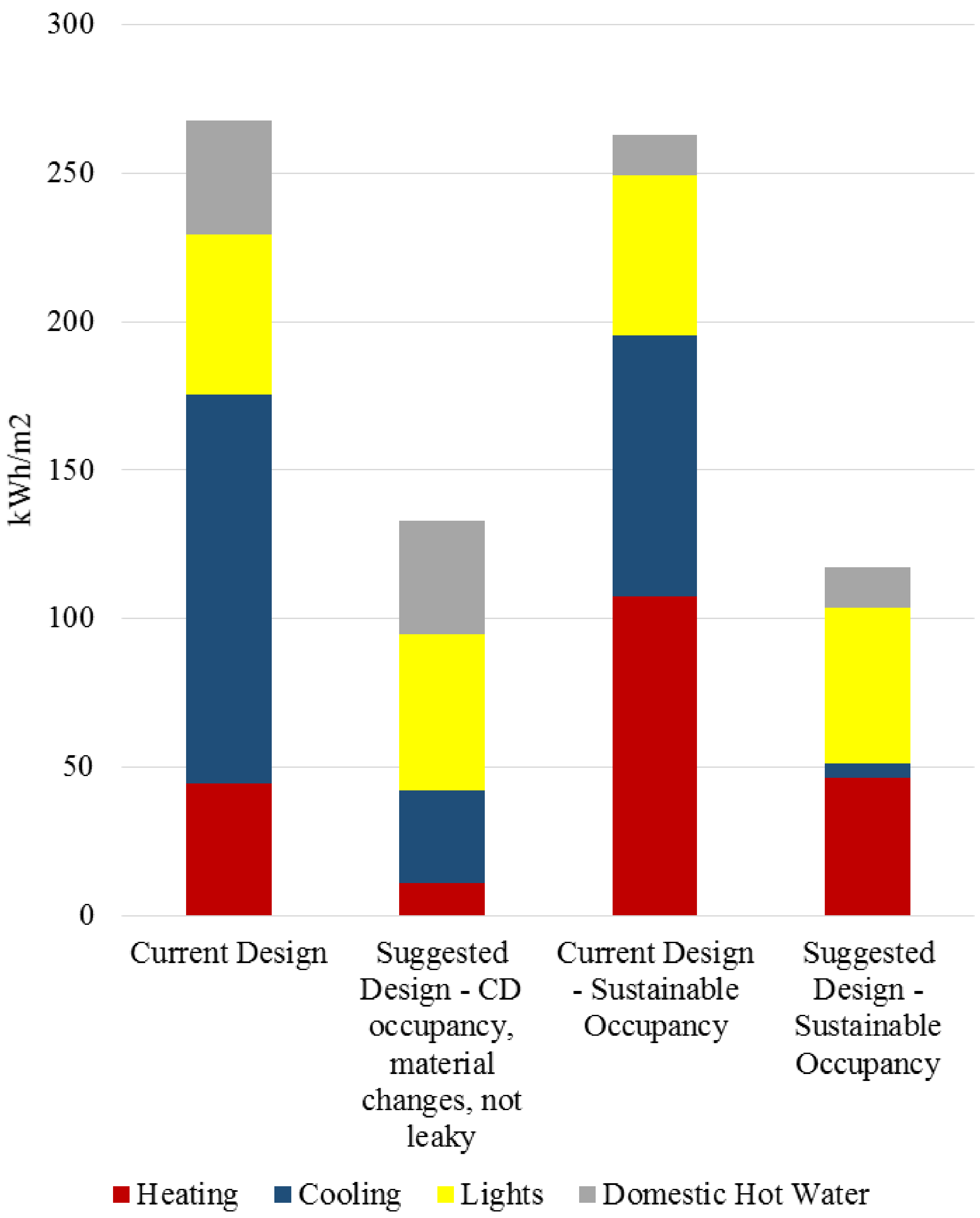

Figure 4.6 Rowhouse - Annual energy consumption

Source: Author

When the model was analysed based on the rowhouse's *current design*, that is to say, no alterations are made to the typical rowhouse building structure or occupancy, it reflected high cooling loads, and low heating loads. As most tenants had already replaced their incandescent light bulbs with more energy efficient ones, the lighting loads remained low, and constant throughout the iterations.

Suggested alterations to the current design (iteration 2) involved building with double brick cavity walls, installing ceilings and making openings more airtight. This considerably reduced the energy required to cool the space and inhabitants (cooling loads) compared to the first iteration. Additional thermal mass for the roof, as per the SANS 10400 XA standard, resulted in a warmer space as well.

An important factor to consider when modelling energy use is the number of people who inhabit each building, or the *occupancy load*. As can be seen in iteration 3, as the number of people in a rowhouse is reduced, the amount of energy required to warm up the space and inhabitants (heating loads) understandably increases. However, with a sustainable occupancy, cooling loads and energy used for domestic hot water use is reduced, compared to iteration 1.

These results are further improved in iteration 4 by combining these interventions (hypothetically limiting the number of residents per rowhouse and making the aforementioned design interventions). The fourth iteration showed the best results, even though the heating load is slightly higher than with the current design (iteration 1), implying that occupancy loads contribute greatly towards thermal comfort.

Table 4.10 Rowhouse – Appliances and lighting

Rowhouse				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
Energy saving lights	12	12	4	210
Electric hob	3000	0,5	1	548
Electric 2-plate stove	1500	1	1	548
Fridge	158	24	1	1384
Kettle	1800	5	1	3285
Phone chargers	9	2	3	20
LCD TV	50	4	1	73

Radio	12	2	1	9
Total average energy consumption based on household appliances, and lighting for one Rowhouse: **6077 kWh/year**				

Source: Author

4.3.2 Maisonette energy consumption

The information documented in 4.2.2 was used to generate a simple model on DesignBuilder.

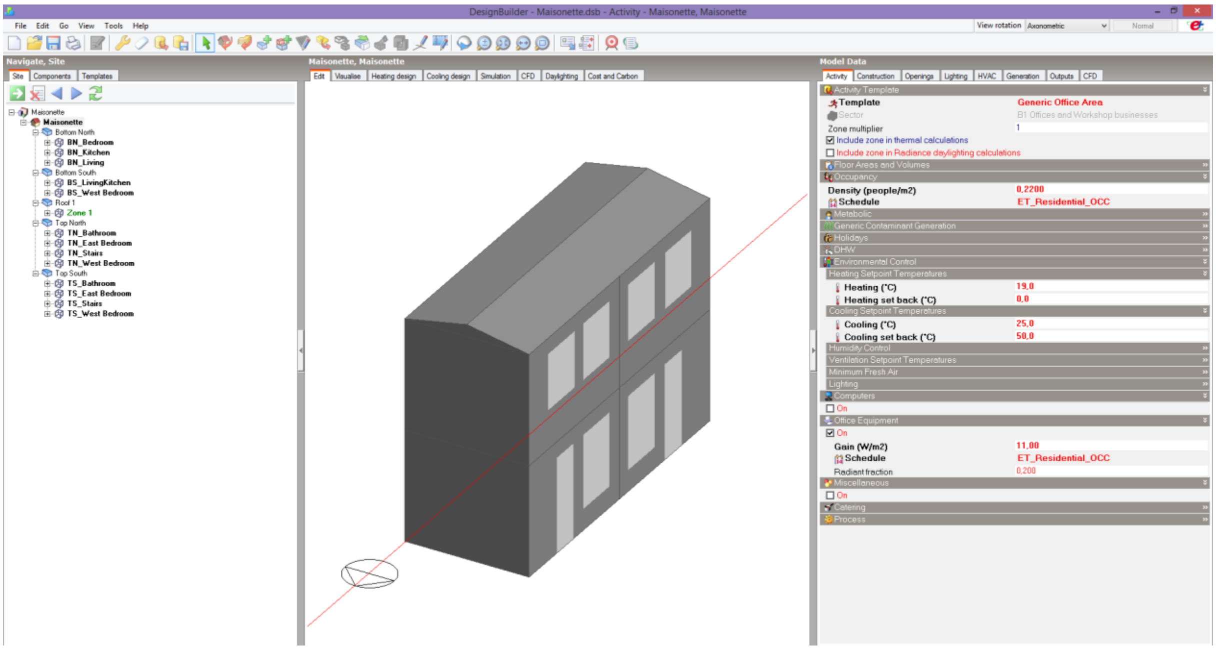

Figure 4.7 Maisonette - DesignBuilder model

Source: Author

The model comprises two double-storey units, and is positioned typically in a north-south axis with east and west facing windows.

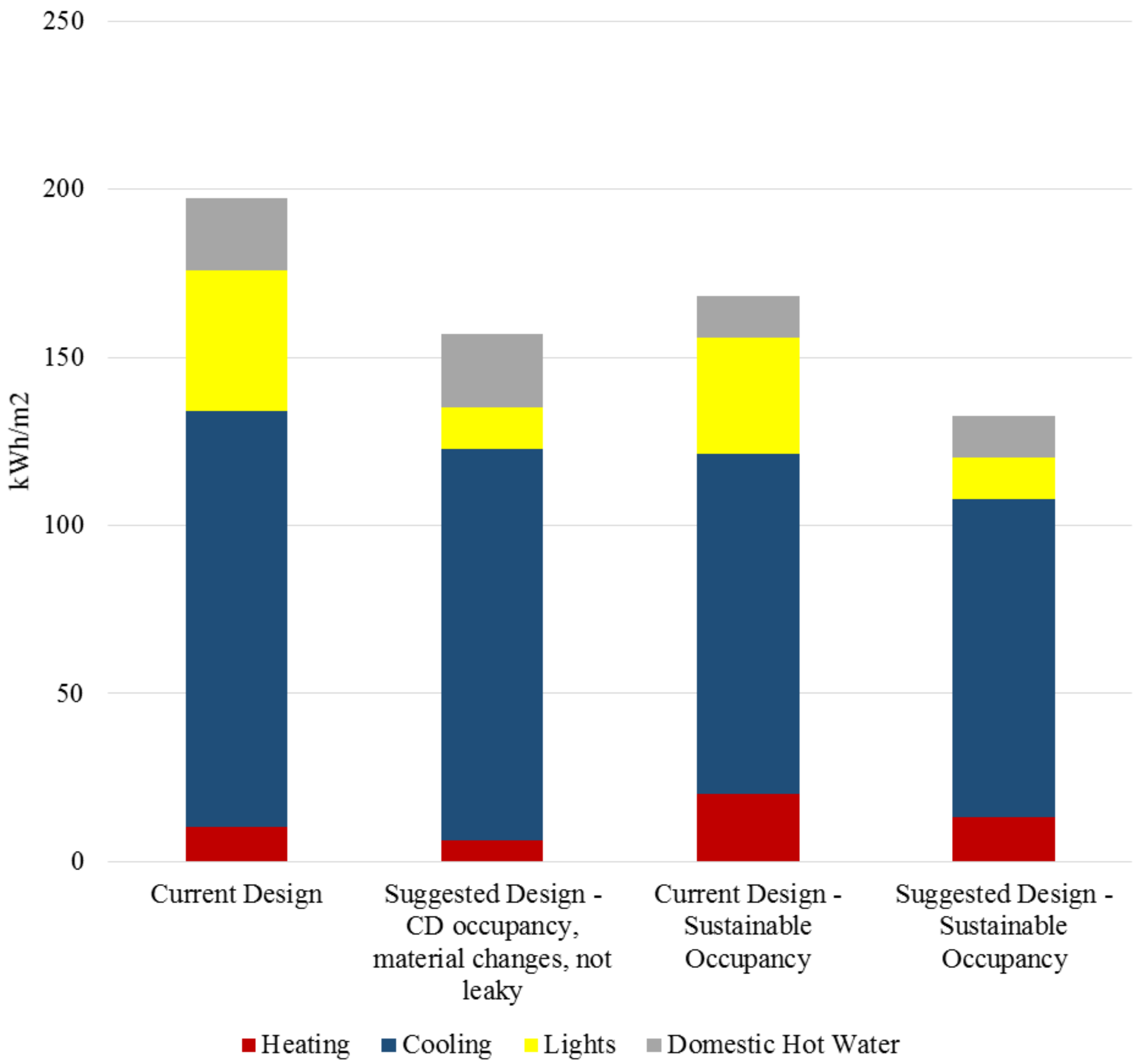

Figure 4.8 Maisonette - Annual energy consumption

Source: Author

The maisonette building currently has high cooling loads *due* to the extra insulation provided by the brick cladding (in addition to structural block walls). As a result of this, the space is naturally quite warm, which means that heating loads are low.

While insulation is usually seen as a positive element, in the case of the maisonettes, this means that the houses remain quite warm during the hot summer months as well. The suggested design makes use of additional thermal mass, but as can be seen in the results of iteration 2, this space might actually benefit from less insulation. An addition which was not previously considered while modelling the iterations, but which has arisen from analysis of the results, is that of shading devices or roof overhangs to counteract the high cooling loads. As the maisonettes were not as severely overcrowded as the rowhouses, courts or hostels, the only difference that occupancy loads seem to make are with regards to the energy required to heat water.

One of the interventions was to replace the types of light bulbs used, and this seems to have improved the results, as can be observed in iterations 2 and 3.

Table 4.11 Maisonette – Appliances and lighting

Maisonette				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
Electric stove*	3000	5	1	5475
Kettle	1800	5	1	3285
Geyser – 150L**	2600	6	1	5694
Washing machine	2500	0,3	1	274
Microwave***	800	0,01	1	3
Tumble dryer	3000	0,5	1	548
Incandescent lights	60	8	5	876
Energy saving lights	12	8	3	105
Phone chargers	9	12	4	158
Ceiling fan****	55	2,5	1	50
LCD TV	50	6	1	110
Radio	12	2	1	9
Total average energy consumption based on household appliances, and lighting for one Maisonette house: **16468 kWh/year**				

Source: Author

*Most residents tend to make use of gas stoves to prevent high electricity costs – as can be seen by the high consumption of electric stoves here.

**Geysers are not common within Manenberg, however, they were installed in the maisonette buildings. Mr Smith was of the impression that leaving his geyser on throughout the day is not as energy intensive as switching it on at regulated times (Smith 2016).

***Hardly ever use the microwave, which is common trend in Manenberg. Smith (2016) and Pascoe (2016) both said they use their microwaves maybe once a week, if that.

****The ceiling fan is used in summer months almost throughout the day because of the high temperatures, possibly due to lack of shading, single glazed windows and no roof overhangs.

4.3.3 Cottages energy consumption

The information documented in 4.2.3 was used to generate a simple model on DesignBuilder.

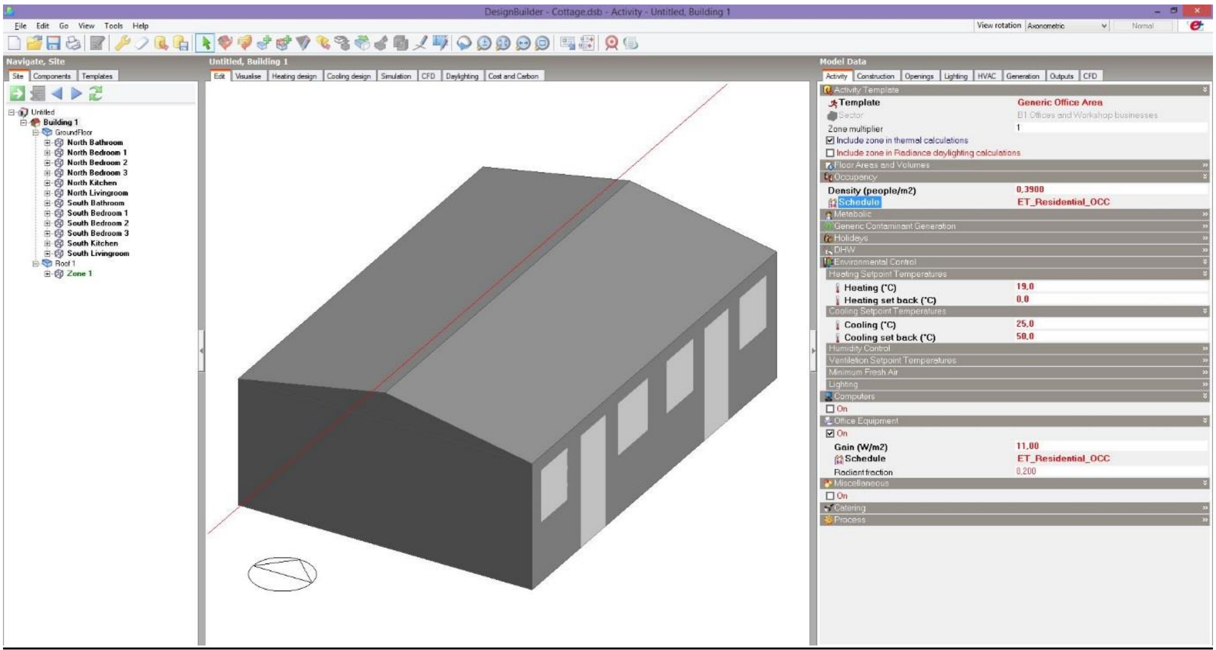

Figure 4.9 Cottages - DesignBuilder model

Source: Author

The model comprises of two standard units, and is positioned typically in a north-south axis with east and west facing windows.

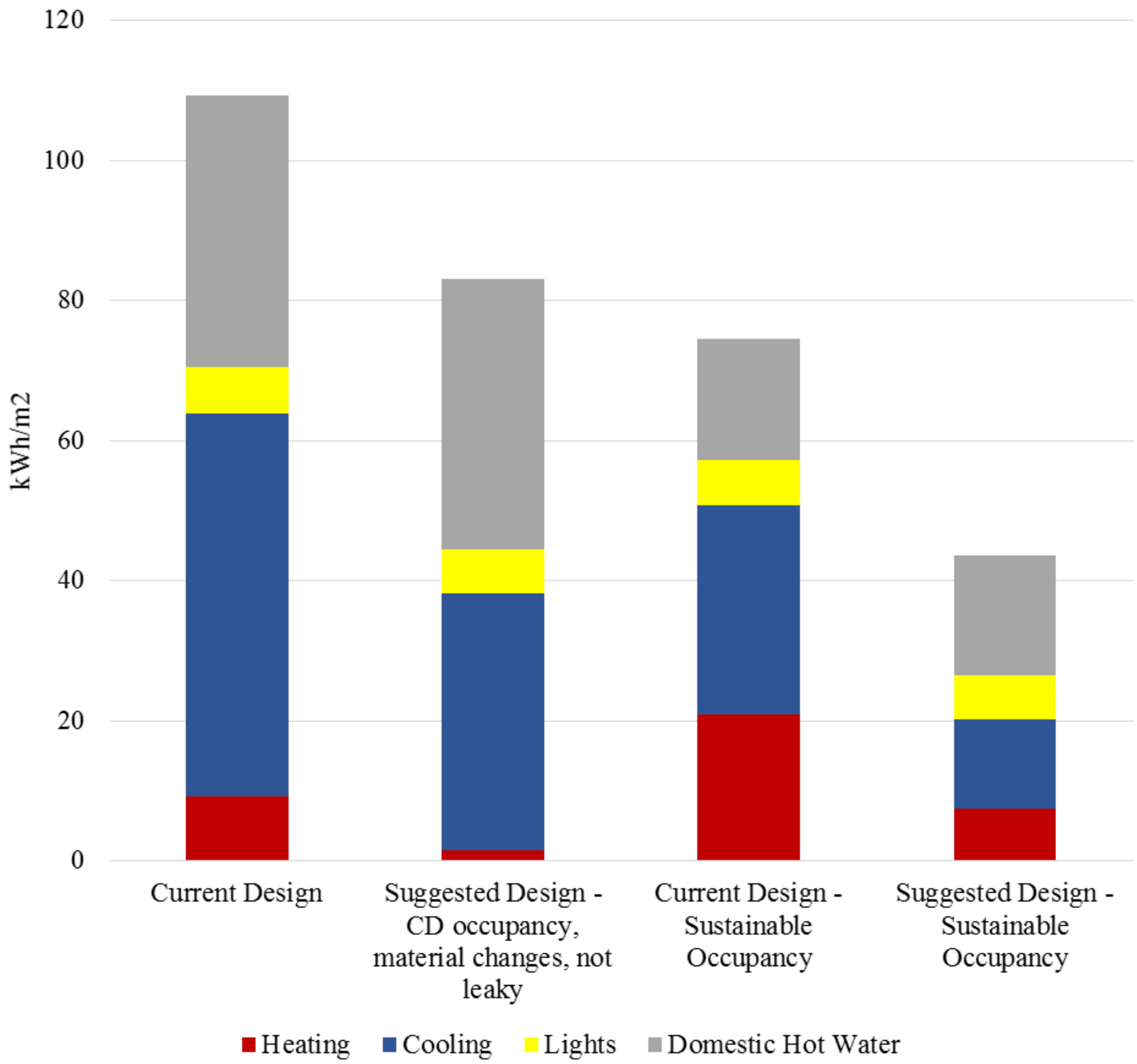

Figure 4.10 Cottages - Annual energy consumption

Source: Author

The high cooling loads observed in iteration 1 (the current design) indicate that the cottages are quite hot inside.

Although the suggested design incorporated SANS 10400: XA approved construction, it can be observed in iteration 2 that these interventions were committed prematurely, and do not meet the needs of the buildings or their users. The consistently high cooling loads imply that a sustainable orientation, along with shading in the form of roof overhangs and window shading devices would prove more helpful. High hot water loads could imply the success of installing solar hot water heaters. As the occupancy loads remain high and the same from iteration 1 to iteration 2, the related domestic hot water energy loads is also great. This implies the potential success of installing solar hot water heaters on these units.

In the third and fourth iterations, the reduction in people per square metre has contributed positively to the domestic hot water related loads, however, this has increased the energy required to heat the space.

When the suggested interventions are applied, in addition to lower occupancy loads, the cottages achieve an overall reduction in annual energy consumption.

Table 4.12 Cottages - Appliances and lighting

Cottage				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
Energy saving Lights	12	12	7	368
Fridge	158	24	1	1384
Kettle	1800	5	1	3285
Phone chargers	9	6	6	118
LCD TV	50	4	1	73
Radio	12	2	1	9
Total average energy consumption based on household appliances, and lighting for one Cottage: **5237 kWh/year**				

Source: Author

4.3.4 Courts energy consumption

The information documented in 4.2.4 was used to generate a simple model on DesignBuilder.

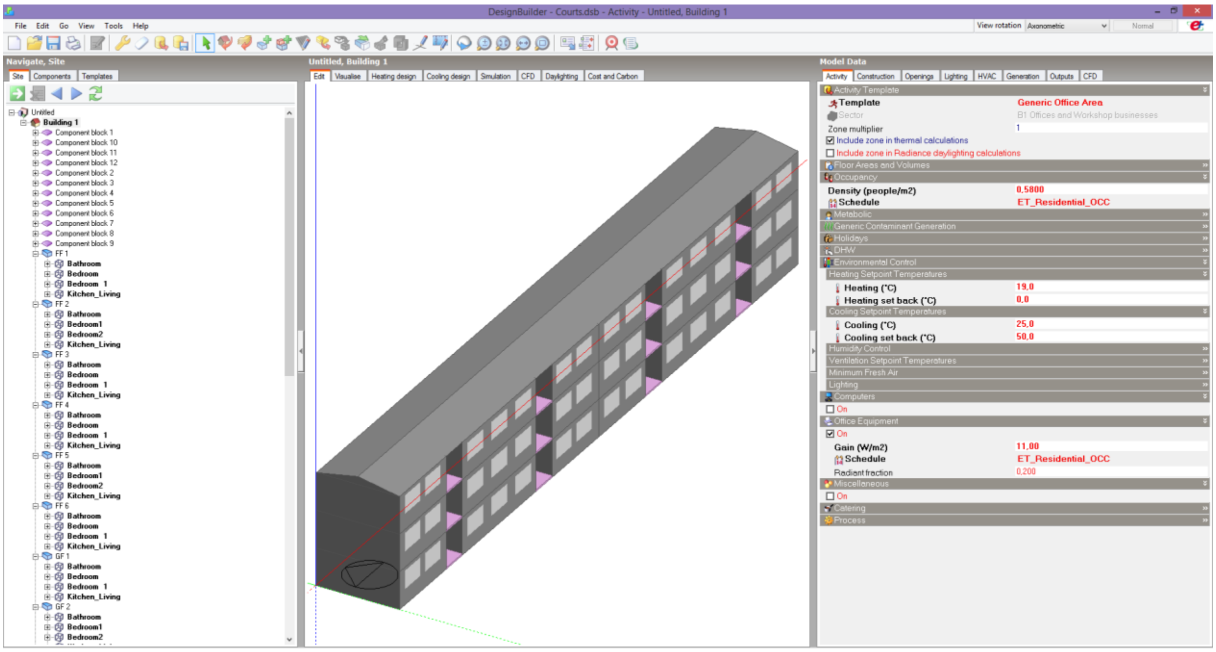

Figure 4.11 Courts - DesignBuilder model

Source: Author

The model comprises three storeys and eighteen units, accessed by four stairwells (these are not modelled as they have no impact on the energy consumption). It is positioned along an east-west axis with north and south facing windows.

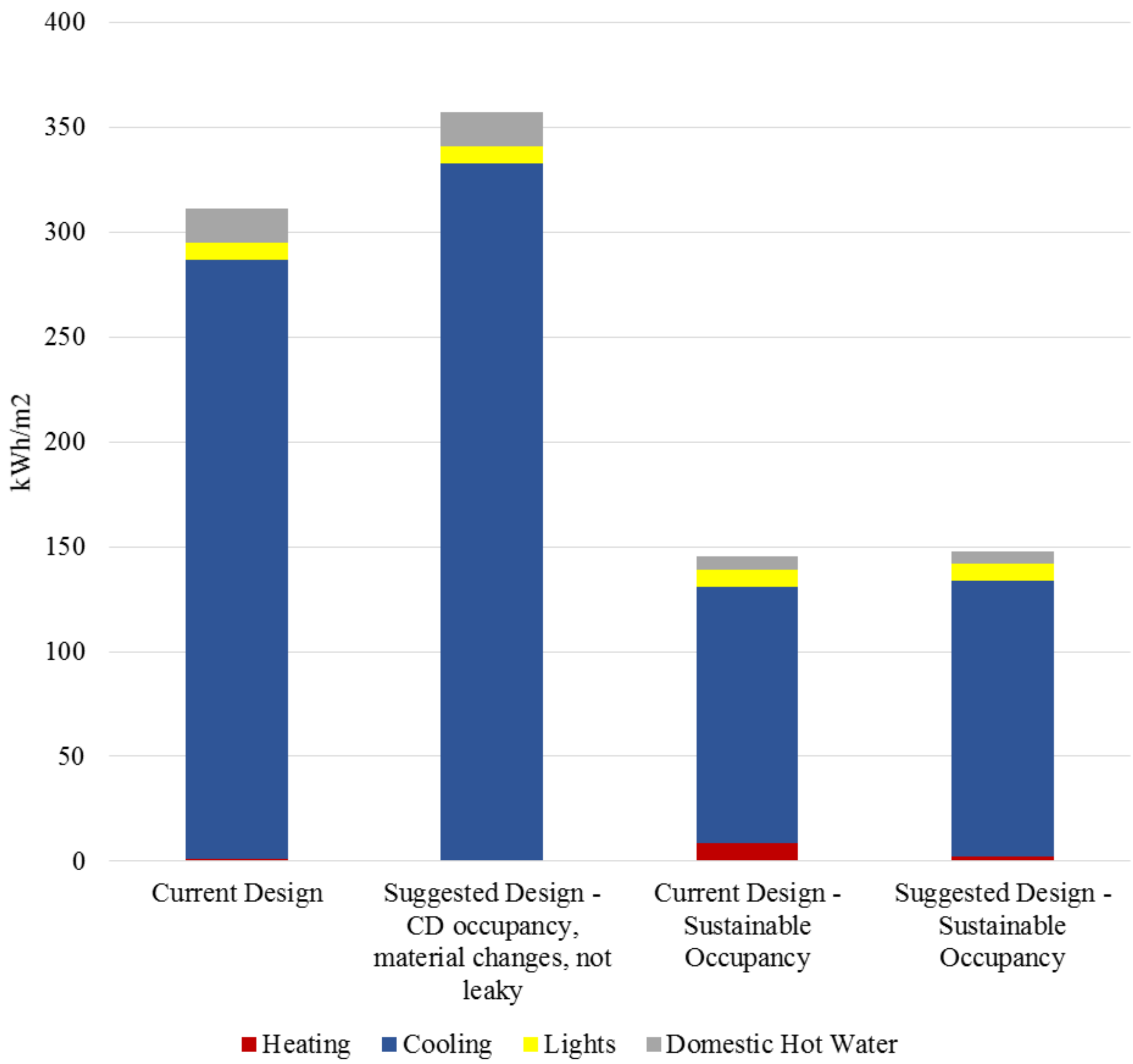

Figure 4.12 Courts - Annual energy consumption

Source: Author

The current design iteration reveals that the courts are incredibly hot, due almost exclusively to the high occupancy loads. This can be ascertained by comparing iterations 1 and 2 with iterations 3 and 4, and by the lack of heating loads. Heating loads are seemingly quite closely related to how many people occupy a single space. The more people per square metre, the lower the heating loads.

The last two iterations indicate that the courts would benefit from sustainable occupancy rates, which in this case has resulted in the reduction of energy consumption by more than half.

The sustainable design interventions which were employed clearly need to speak to the requirements of the buildings and its context, and not as standalone interventions based only on national standards. As can be seen in the iteration 2 and 4, the cooling loads go up, which implies that the heat is further trapped by the insulated rooms.

Table 4.13 Courts - Appliances and lighting

Courts				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
Energy saving Lights	12	12	5	263
Fridge	158	24	1	1384
Kettle	1800	5	1	3285
Phone chargers	9	6	4	79
LCD TV	50	4	1	73
Radio	12	6	1	26
Hair straightener*	600	0,5	1	110
Microwave	800	0,1	1	29
100L urn**	2000	2	1	1460
Total average energy consumption based on household appliances, and lighting for one court apartment: **6709 kWh/year**				

Source: Author

*Hair straighteners were always one of the first appliances mentioned when asked which ones they use most regularly, or at least every day.

**Large hot water urns were provided to low income earners in Manenberg, but the residents do not like to use them because of their high energy consumption, the time it takes to heat them up versus how many people can use the hot water to bath. As a result, kettles remain a popular alternative for providing hot water, even for bathing purposes. Most residents responded that they use two 1,5L kettles per person, two or three times a week, for bathing.

4.3.5 Government Reconstruction and Development Programme house energy consumption

The information documented in 4.2.5 was used to generate a simple model on DesignBuilder.

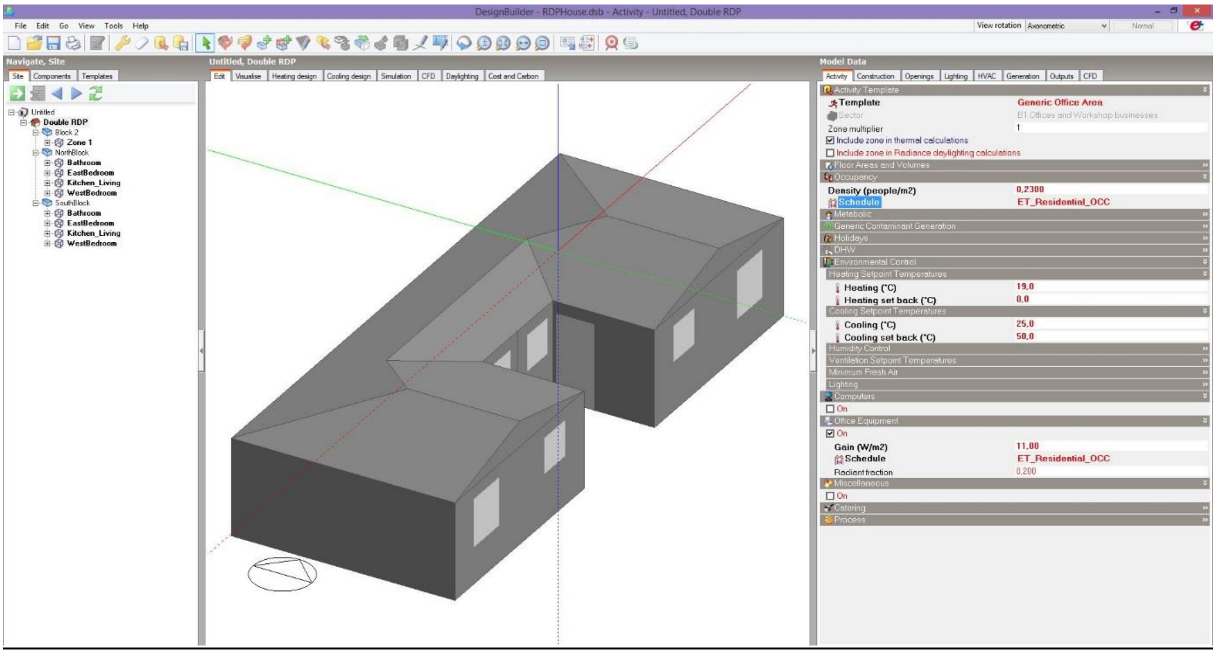

Figure 4.13 Government Reconstruction and Development Programme House - DesignBuilder model

Source: Author

The model comprises two units which share a wall, and is positioned typically in a north-south axis with east and west facing windows.

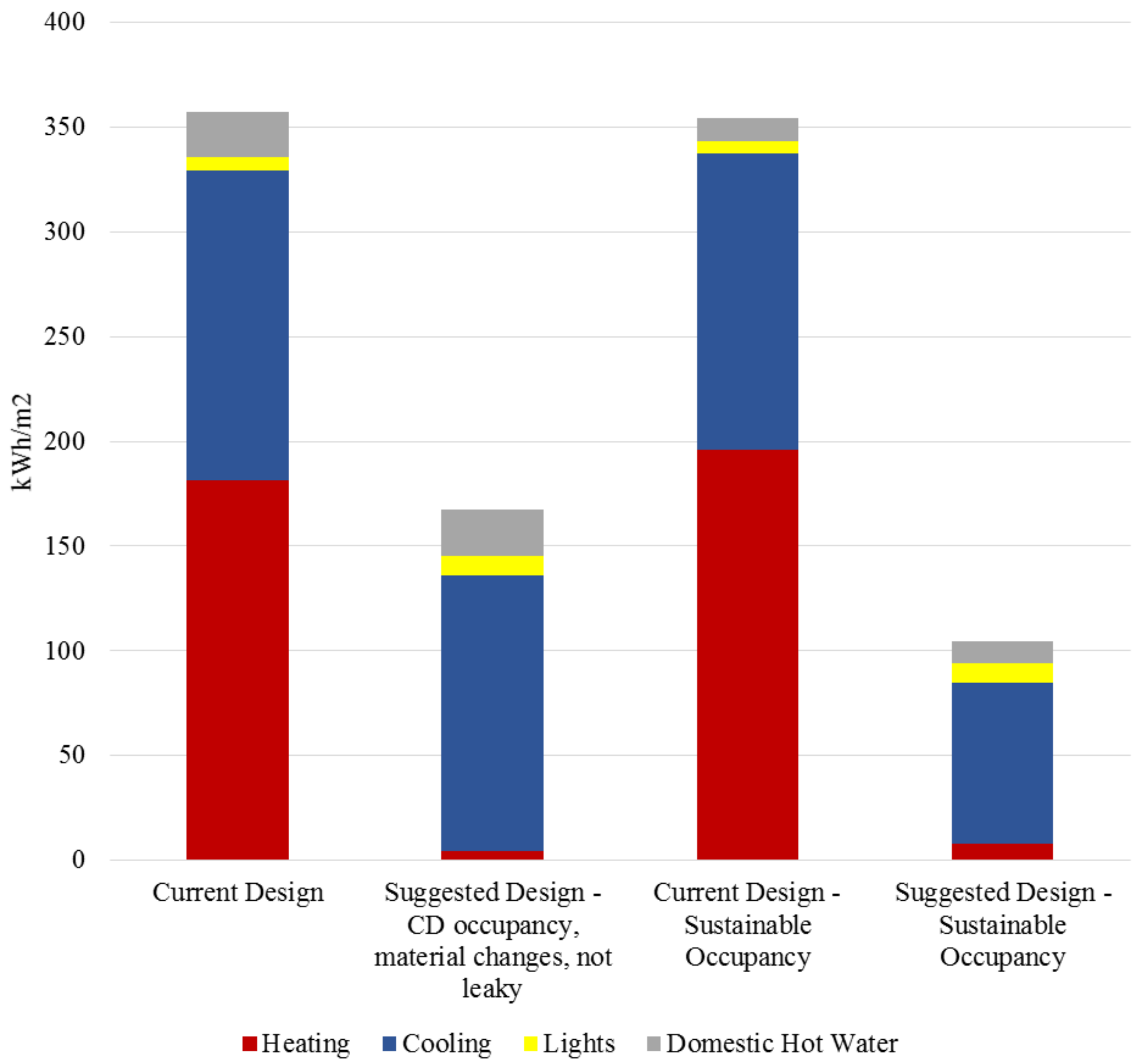

Figure 4.14 Government Reconstruction and Development Programme House - Annual energy consumption

Source: Author

Unlike with the courts, occupancy loads have no influence on the energy consumption of the Reconstruction and Development Programme houses, as can be noted by the lack of significant difference between iterations 1 and 3, and iterations 2 and 4. This is likely due to the fact that the houses are already occupied sustainably. However, thermal inefficiency of the current design results in high heating loads and similarly high cooling loads.

By incorporating changes recommended for iteration 2 and 4, such as insulating the building and adding ceilings, the energy loads are cut in half. It is, however, apparent from Figure 4.14 that the typical orientation of these buildings and the incorporation of shading devices should be further investigated to see a successful reduction in cooling loads.

Table 4.14 Government Reconstruction and Development Programme House - Appliances and lighting

Government Reconstruction and Development Programme House				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
Incandescent lights	60	8	5	876
Fridge	158	24	1	1384
Kettle	1800	5	1	3285
Phone chargers	9	6	6	118
LCD TV	50	4	1	73
Radio	12	2	1	9
Total average energy consumption based on household appliances, and lighting for one Reconstruction and Development Programme house: **5745 kWh/year**				

Source: Author

4.3.6 Migrant labour hostel (1-storey) energy consumption

The information documented in 4.2.6 was used to generate a simple model on DesignBuilder.

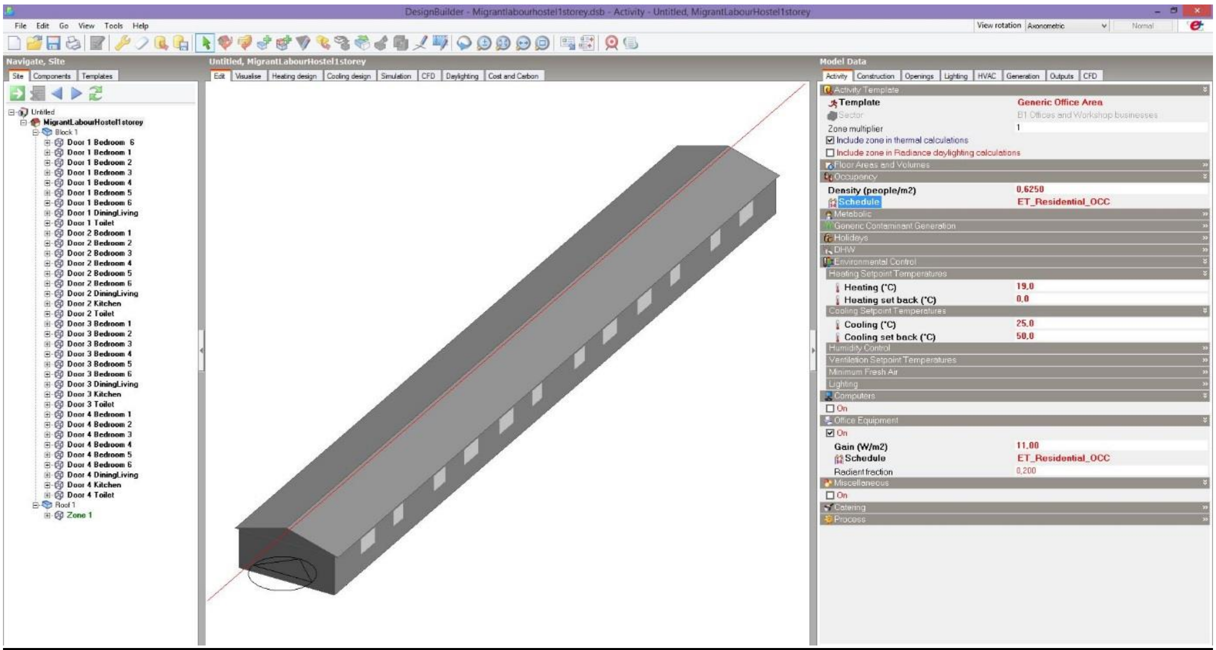

Figure 4.15 Migrant Labour Hostel (1-storey) - DesignBuilder model

Source: Author

The model comprises a single storey, with four *doors*. It is positioned typically on a north-south axis with east and west facing windows.

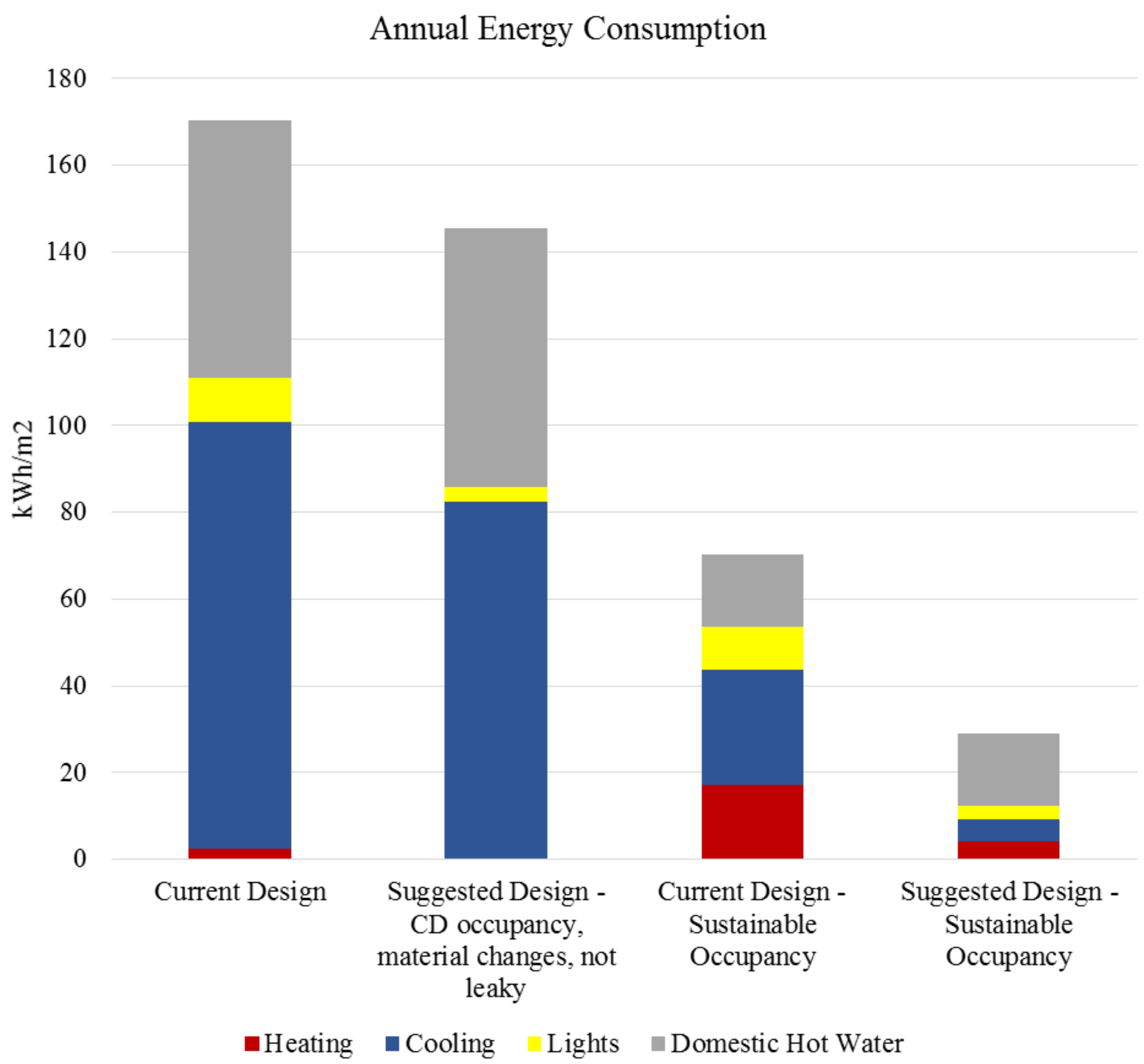

Figure 4.16 Migrant Labour Hostel (1-storey) - Annual energy consumption

Source: Author

The first and second iterations depict how overcrowded the single storey hostels really are. The high cooling loads are almost directly proportionate to the high occupancy rates and the typical orientation of the buildings, explained in 4.2.6. With the high occupancy rate is the high domestic hot water use. This might suggest the usefulness of installing solar hot water heaters on these buildings.

Occupancy loads are the biggest challenge in hostels. As can be seen in iterations 3 and 4, a reduction of occupancy loads has made a noticeable impact on thermal comfort. One of the suggestions for improved design is to make the openings airtight. It can be observed in the second iteration that this only served to keep the building hot inside. While the cooling loads decrease, they remain high. Along with some of the more context specific design interventions such as changing to fluorescent lighting and incorporating SANS 10400:XA approved construction, if the occupancy is made more sustainable, the potential overall energy consumption per year can be observed in the last two iterations.

Table 4.15 Migrant Labour Hostel (1-storey) - Appliances and lighting

Migrant Labour Hostel 1-storey*				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
Incandescent Lights	60	8	10	1752
Kettle	1800	4	3	7884
Fridge	158	24	1	1384
2-plate stove	1500	2	3	3285
Electric hob**	3000	0,3	1	329
Hot water urn 30L***	2000	0,1	1	73
Phone chargers	9	0,1	20	7
CRT TV	80	6	4	701
Radio	12	12	3	158
Microwave	800	2	2	1168
Total average energy consumption based on household appliances, and lighting for one MLH 1-storey: **16741 kWh/year**				

Source: Author

*This data is for an entire *Kwakiki* one-storey hostel. Each bedhold pays upwards of R100 a month for electricity.

**Electric hob is only used for baking purposes (once a month), as it is too expensive for daily use.

***Unlike with most households, the tenant bought a 30L hot water urn for her family, which, while energy-intensive, saves them water and electricity when compared to the traditional use of kettles instead. In the school months, she boils thirty litres every morning for all hot water needs. During the day, she uses the microwave for heating water for tea.

4.3.7 Migrant labour hostel (2-storey) energy consumption

The information documented in 4.2.7 was used to generate a simple model on DesignBuilder.

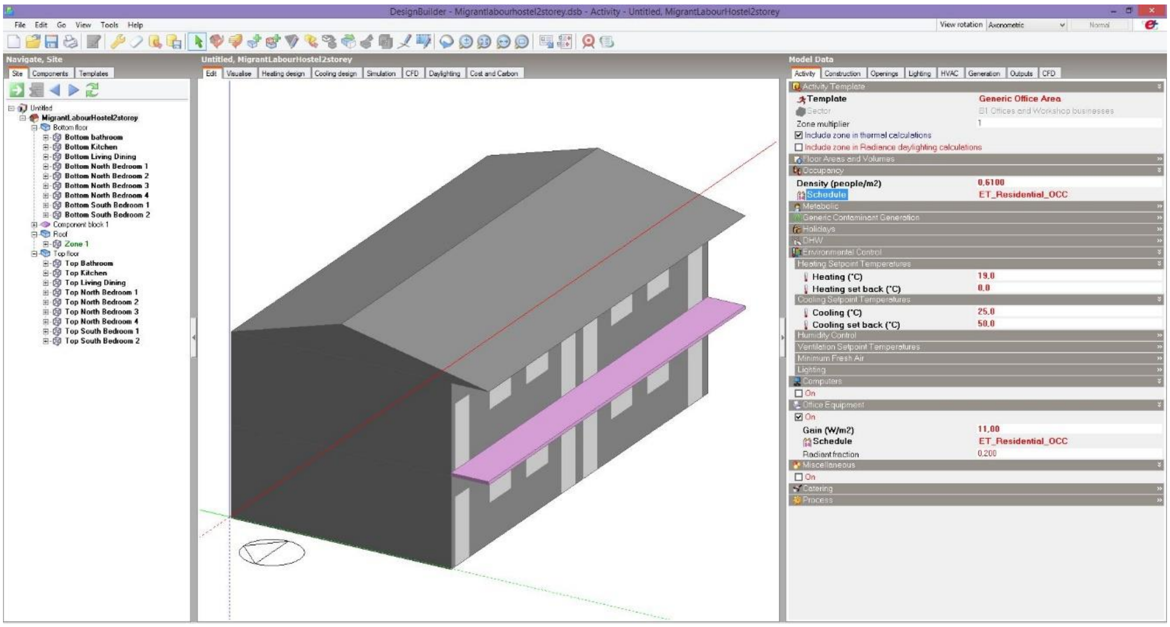

Figure 4.17 Migrant Labour Hostel (2-storey) - DesignBuilder model

Source: Author

The model comprises of two units over two floors, with a small roof overhang and balcony space indicated. It is positioned in east-west axis with north and south facing windows.

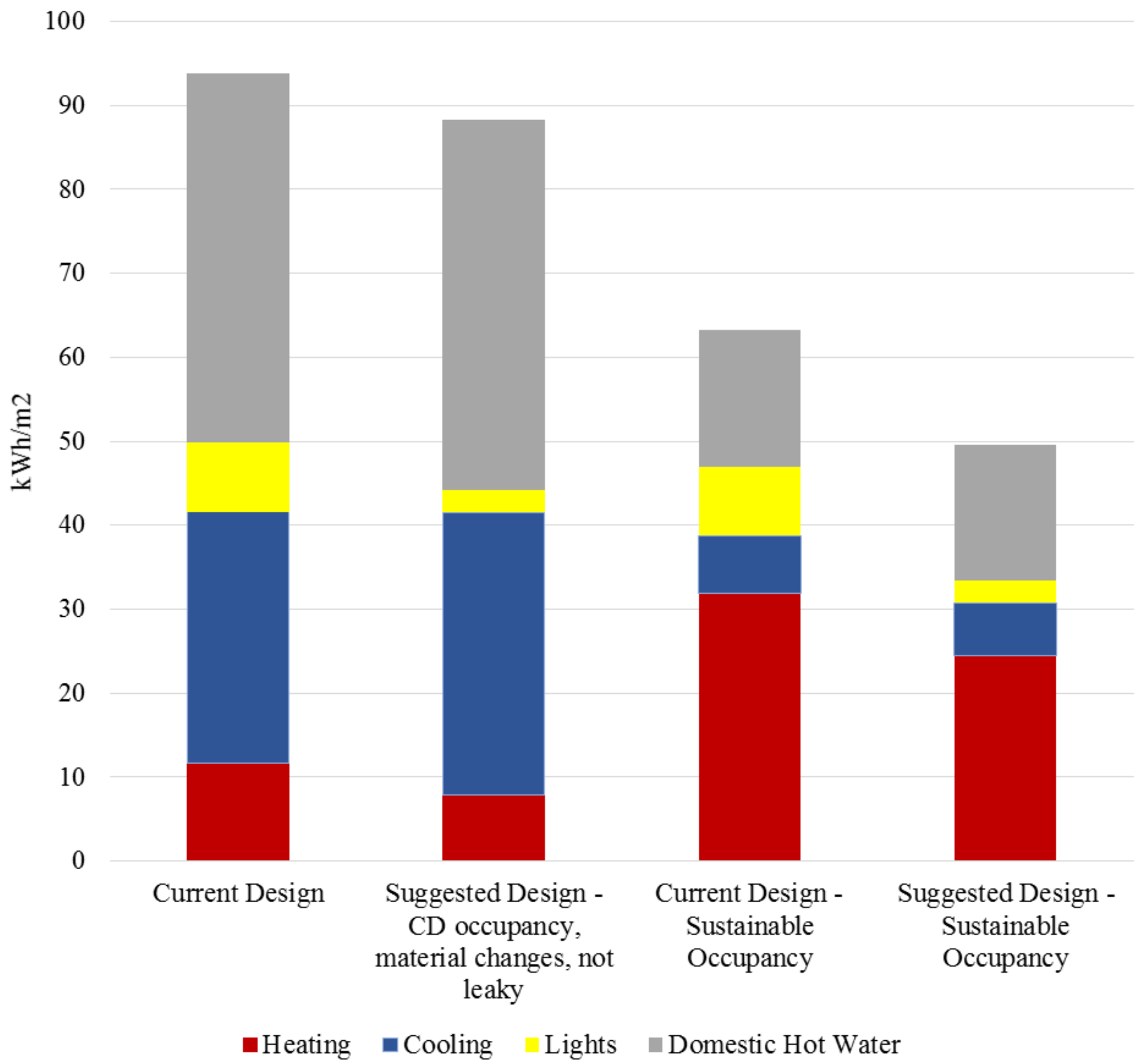

Figure 4.18 Migrant Labour Hostel (2-storey) - Annual energy consumption

Source: Author

In iterations 1 and 2 it can be observed that the domestic hot water loads are high. When compared to iterations 3 and 4, it becomes apparent that this is due to high occupancy loads. If these loads cannot be improved, then the installation of solar hot water heaters would prove very useful on these buildings.

Iteration 2 and 4 reveal the benefits of switching to more efficient lighting as the lighting density is reduced by more than half. Structural design interventions would make the space slightly warmer than it currently is.

While the high occupancy loads have a direct and obvious effect on the amount of energy used to heat water, the effect on space heating is curious. As can be seen in iterations 3 and 4, when the occupancy loads were made sustainable, the need to heat the space more than doubled, because people currently contribute greatly towards keeping the space warm. The reduction in occupancy may be comfortable in summer. However, it would be very uncomfortable during the winter months.

The incorporation of design interventions and reduction of occupancy loads seems to result in a lower overall energy consumption per year, even though thermal comfort is arguable.

Table 4.16 Migrant Labour Hostel (2-storey) - Appliances and lighting

Migrant Labour Hostel 2-storey				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
Incandescent Lights	60	8	20	3504
Fridge	158	24	2	2768
Kettle	1800	8	1	5256
Phone chargers	9	6	20	394
LCD TV	50	4	2	146
Radio	12	6	3	79
Total average energy consumption based on household appliances, and lighting for one MLH 2-storey: **12147 kWh/year**				

Source: Author

4.3.8 ‘2-storey’ energy consumption

The information documented in 4.2.8 was used to generate a simple model on DesignBuilder.

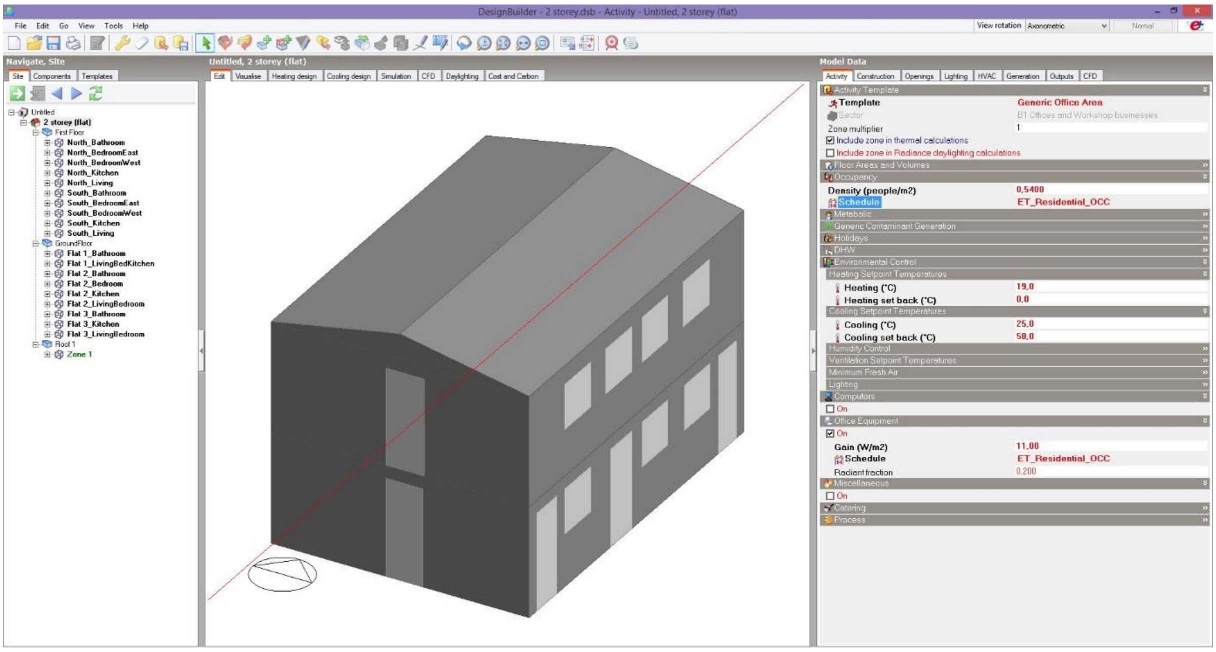

Figure 4.19 ‘2-storey’ - Designbuilder model

Source: Author

The model comprises five units: two flats on the top floor accessed from the sides, and three flats on the ground floor. It is positioned typically on a north-south axis with east and west facing windows.

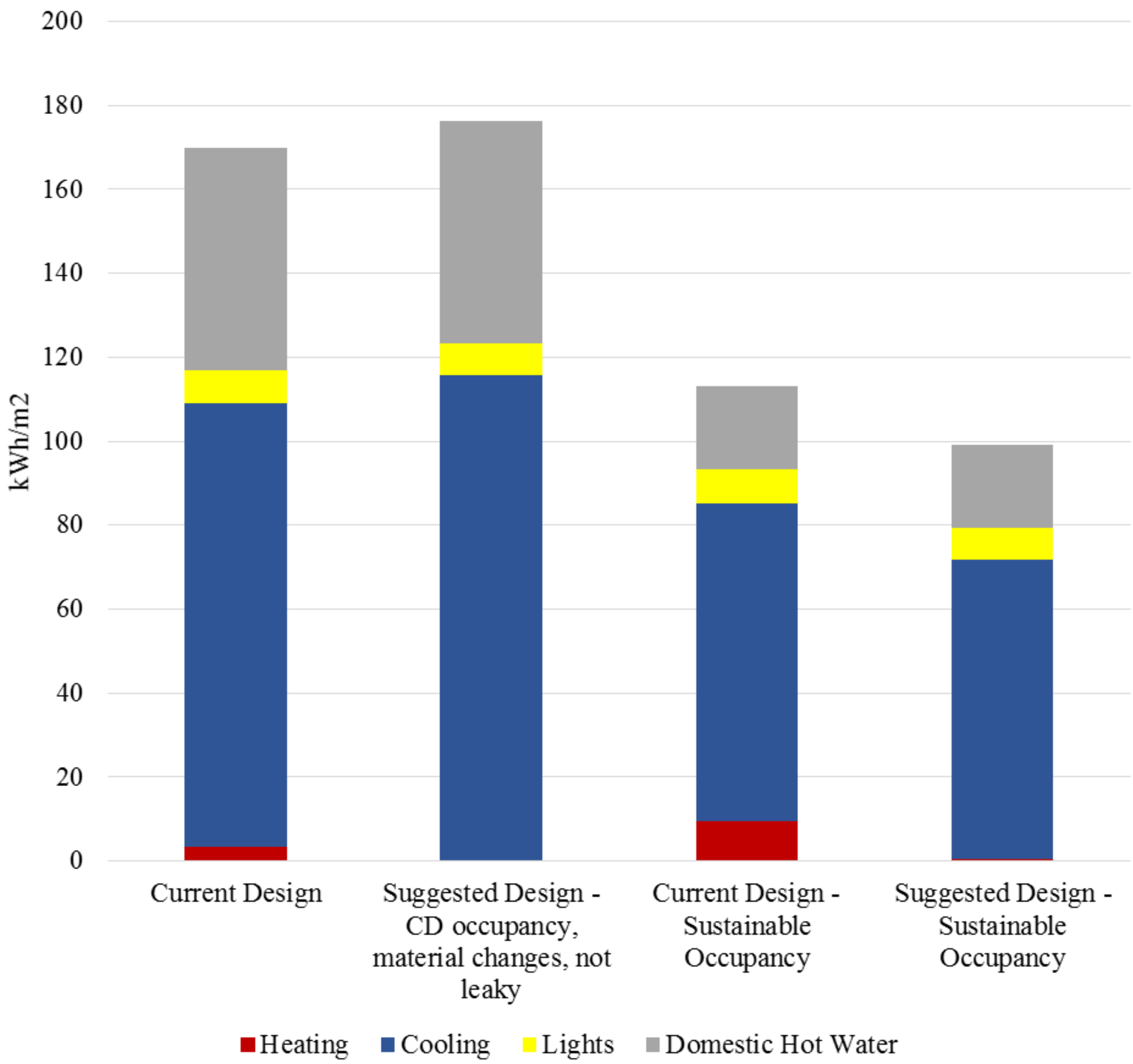

Figure 4.20 '2-storey' - Annual energy consumption

Source: Author

As can be observed from Figure 4.20, the '2-storeys' have very high cooling loads. This could be attributed to the occupancy rates, but more so to the lack of shading and the poor orientation of the current design. The rooms lack cross-ventilation capabilities due to their layouts, and this traps the hot air inside.

The design interventions were run before the consumption of the current design could be run, and therefore the standards-specified intervention were not sufficient for improving the energy profiles of the buildings, as can be seen by the lack of significant improvement in the later iterations. This is a lesson in the need to provide context-specific, case-by-case upgrades.

The high hot water use could imply the usefulness of installing solar hot water heaters on these buildings.

Iterations 3 and 4 indicate that lowering the occupancy has a significant impact on the energy loads, even though cooling loads remain a concern. It is suggested that future interventions also incorporate shading devices and white roofs to combat the hot interiors, even though iteration 4 shows a marked overall improvement from the previous iterations.

Table 4.17 '2-storey' - Appliances and lighting

'2-storey'				
Appliance	**Power use (Watts)**	**Hours/Day in use**	**Number of appliances**	**Ave kWh per year**
	A	B	C	=AxBxC/1000x365
CRT TV	80	1	1	29
Fridge	158	24	1	1384
Kettle	1800	5	1	3285
Phone chargers	9	6	4	79
Energy Saving lights	12	12	5	263
Desktop, LCD Monitor	250	8	1	730
Microwave	800	0,01	1	3
Electric hob	3000	0,7	1	767
Laptop	55	2	1	40
Total average energy consumption based on household appliances, and lighting for one 2-storey: **5770 kWh/year**				

Source: Author

4.4 Typologies of representative low-cost building types based on energy consumption profile in Gugulethu and Manenberg

The third objective required the buildings identified in 4.2 and the energy profiles shown in 4.3 to be combined in order to develop typologies of buildings based on their energy profile.

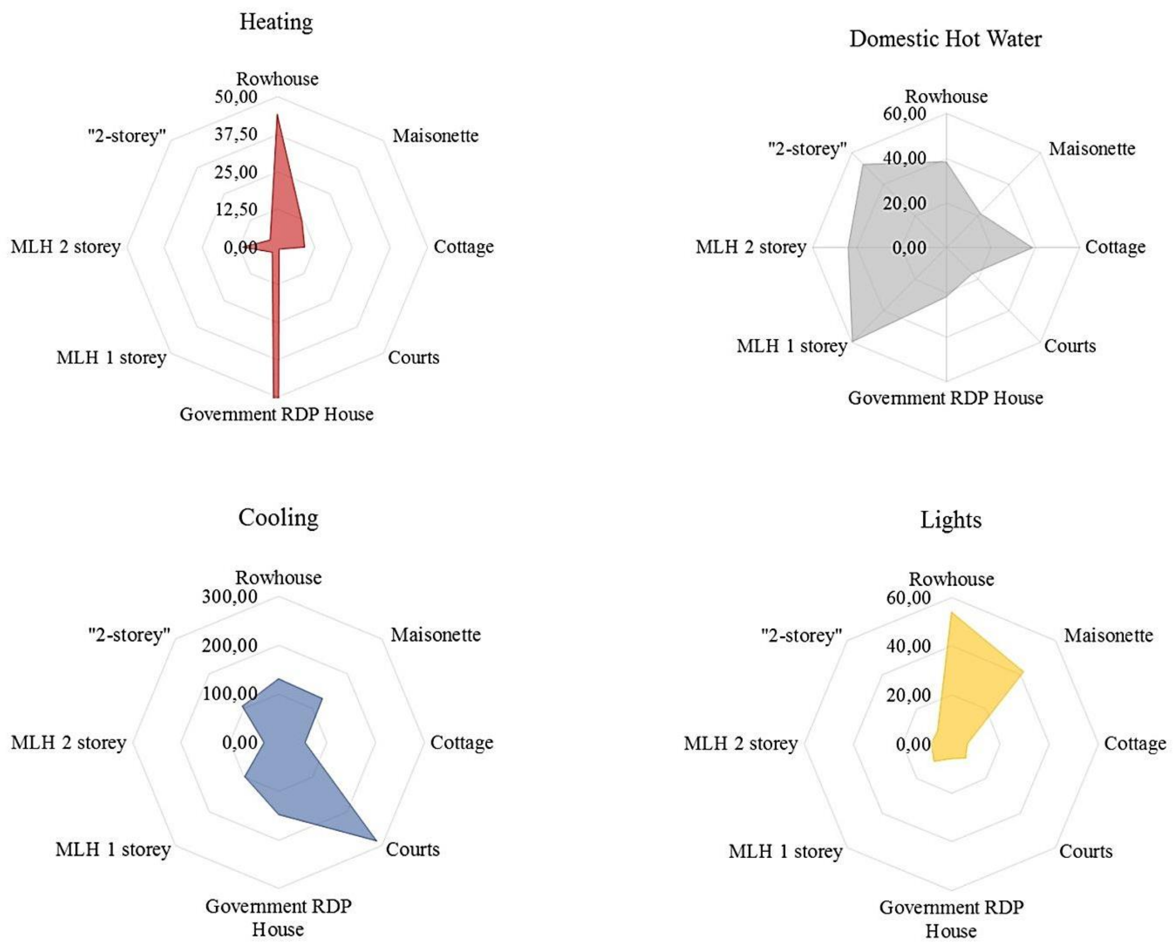

Figure 4.21 Energy modelling summarised findings (kW/m²/year)

Source: Author

The results from the energy modelling revealed that cooling loads contributed most to energy consumption based on the existing building designs. This means that the buildings are very hot, especially the courts buildings. The Reconstruction and Development Programme house has equally high heating and cooling loads, which makes it the most thermally inefficient of all the building types investigated. That being said, none of the building types are efficient.

Lighting remains a high contributor in buildings which still make use of incandescent lights. To this end, the newly renovated and constructed buildings, such as the courts, government Reconstruction and Development Programme houses and single storey migrant labour hostels can be seen to have very low lighting loads.

The heating loads are very low in this chart due to the high occupancy loads of the original designs. These have been noted to go up once sustainable occupancy is applied.

Domestic hot water is one of the sources of high energy consumption, and opens up the possibility of incorporating alternative energy sources in this regard. Solar hot water heaters would be highly beneficial for all the buildings, but especially the migrant labour hostels and the ‘2-storey’ buildings, which rely heavily on kettles for domestic hot water for incredibly high populations.

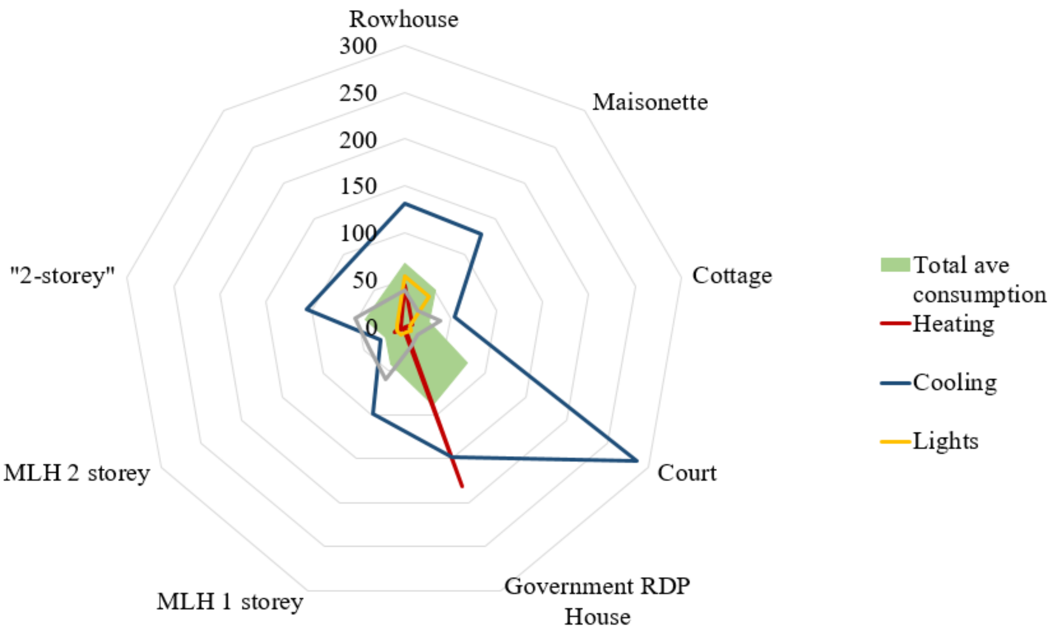

Figure 4.22 Energy consumption per source per type, compared to average energy consumption

Source: Author

Even though some buildings such as the rowhouse and government Reconstruction and Development houses tend towards lower heating, lighting and domestic hot water loads, their overall average energy consumption is comparable to high consumption buildings such as the courts. In an attempt to distinguish them based on their energy consumption, the buildings were categorised into low, medium and high consumption typologies. For each of the separate loads, lighting revealed a low consumption profile amongst all the buildings. In terms of percentages, there were no high consumers in any of the categories, except for the big courts buildings. Heating was also revealed to have relatively low profiles, except for a slightly higher RDP house reading. However, these results were more indicative of reality when they were sorted according to their overall consumption profiles, the ranges for which were more relative.

Table 18 Typology of buildings per energy profile

Similar consumption profiles (%)	**Typology 1 Low Consumption Profile (0-33%)**	**Typology 2 Medium Consumption Profile (34-66%)**	**Typology 3 High Consumption Profile (67 - 100%)**
Heating	Maisonette; cottage; court; MLH 1 storey; MLH 2 storey; '2-storey'; Rowhouse	Government RDP house	
Cooling	MLH 2storey	Rowhouse; cottage; Government RDP House; '2-storey'; Maisonette; MLH 1storey	Courts
Lighting	Courts; Government RDP House; '2-storey'; Cottage; MLH 1 storey; MLH 2 storey; Rowhouse; Maisonette		
Domestic Hot Water	Rowhouse; Maisonette; Courts; Government RDP House; '2-storey'	Cottage; MLH 1storey; MLH 2-storey	
Overall Consumption Profiles (kW/m²/year)	**Low Consumption Typology (0-30)**	**Medium Consumption Typology (31-60)**	**High Consumption Typology (60+)**
	Cottages; MLH 2 storey	**Maisonette; MLH 1 storey; 2-storey**	**Rowhouse; Courts; RDP**

Source: Author

The buildings which formed part of the low consumption typology were the cottages and the two-storey migrant labour hostels. The medium consumption typology consisted of the maisonettes, the single storey migrant labour hostels and the '2-storey' buildings. The high consumption typology was developed for the rowhouse, courts and government Reconstruction and Development Programme houses. It should be noted that these consumption typologies refer only to the energy consumption, and not to the thermal comfort of the spaces. This means that even if a building is part of the low consumption typology, it is not necessarily thermally efficient or comfortable.

4.5 Limitations of conventional and alternative energy systems within the low-cost building sector in South Africa

The results of the final research objective were based on the analysis of the results of the previous objectives. Thermal gains graphs were employed to determine what the largest consumers of energy were per building type, using existing data. These were useful for indicating what changes (in terms of energy systems, technologies available and building design) are required within township buildings to transition towards an energy efficient, sustainable built environment.

4.5.1 Thermal gains per building type

Thermal or internal gains refers to the amount of heat generated or lost within a space due to features such as the building's structure; solar radiation; occupancy, lighting or equipment loads (the number of people, lights or appliances per square metre), and other design features such as shading devices, roof overhangs, ceilings, and so on. The thermal gains graphs were generated for the current design models of each of the buildings in order to determine where heat was being lost or gained, in order to address those features directly. Space heating and cooling assumes a large portion of building energy consumption. Therefore the graphs depicted in sections 4.5.1.1 to 4.5.1.8 are useful for determining how to lower the buildings' energy profiles. In order to read these graphs, it is necessary to highlight that they are cumulative area graphs. What this means is that the area of each type of thermal gain is what determines its impact. That is to say, the bigger the visual area of the specific thermal gains, the bigger its impact.

The thermal gains were measured in Watt-hours per square metre (Wh/m²). The thermal gains were calculated over a single week in summer, and again in winter. The model was set to show the thermal gains for week 5 of the year for the summer months (usually the first week of February), and week 27 of the year for the winter months (usually the first week of July). Table 4.19 describes what each of the gains depicted represent, and in what colour they are organised according to the legend.

Table 4.19 Thermal gains graph descriptions

Thermal gain/loss	Colour on legend	Description
People	*Lilac*	The heat contribution of the number of people per square metre (occupancy load) to the space.
Lights	*Gold*	The heat contribution of the number of lights (Watts) per square metre (lighting density) to the space.
Equipment	*Bright green*	The heat contribution of the number of appliances (Watts) per square metre (equipment load) to the space.
Infiltration gain	*Blue*	Air leakage which causes outside temperatures to be higher than inside temperatures
Convection gain	*Maroon*	The heat transmitted into the space by walls and roofs
Window gain	*Pink*	The heat transmitted into the space through windows
Window loss	*Moss Green*	The heat lost in a space through windows
Infiltration loss	*Purple*	Airtightness which causes outside temperatures to be lower the inside temperatures
Convection loss	*Red*	The heat lost in a space because of walls and roofs

Source: Author

4.5.1.1 Rowhouse thermal gains

These thermal gains graphs were generated using the West facing bedroom in the northern flat on the top floor.

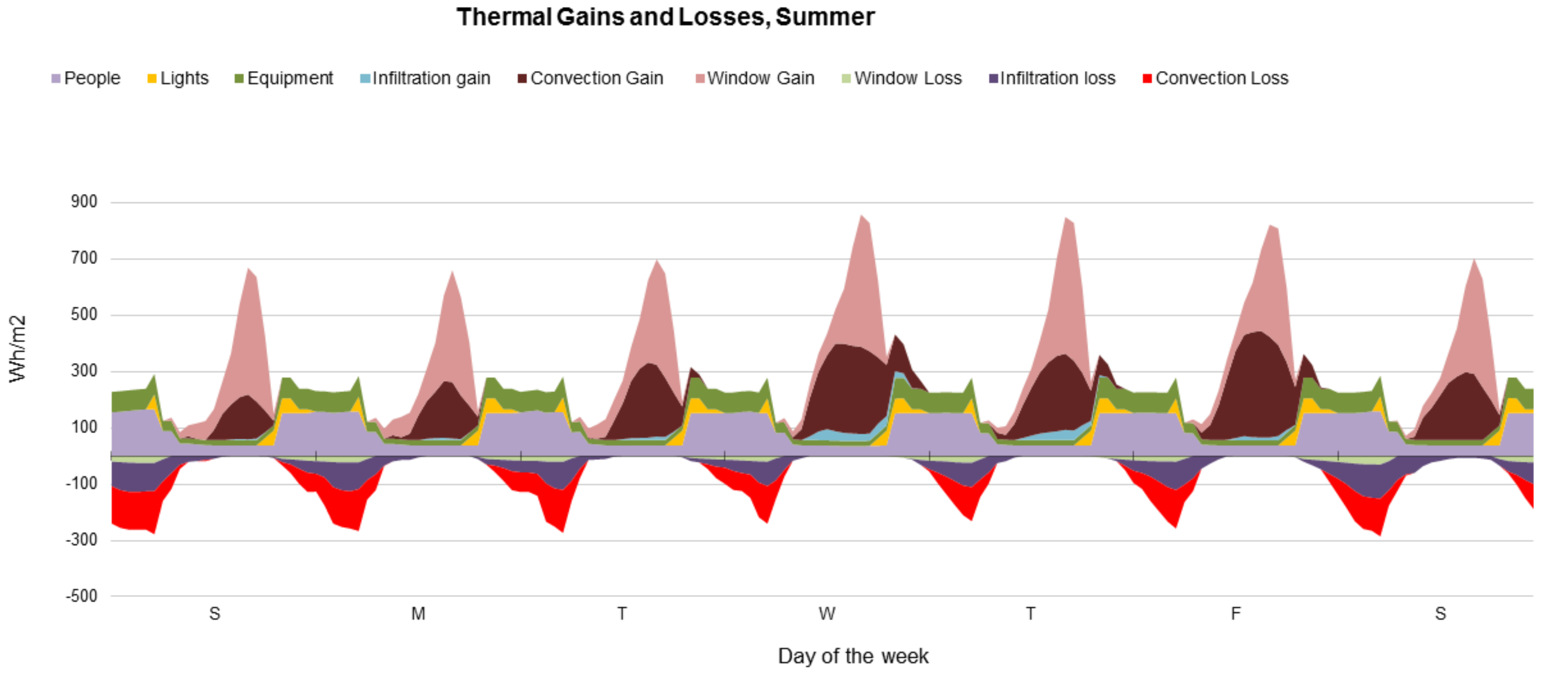

Figure 4.23 Rowhouse thermal gains and losses in summer

Source: Author

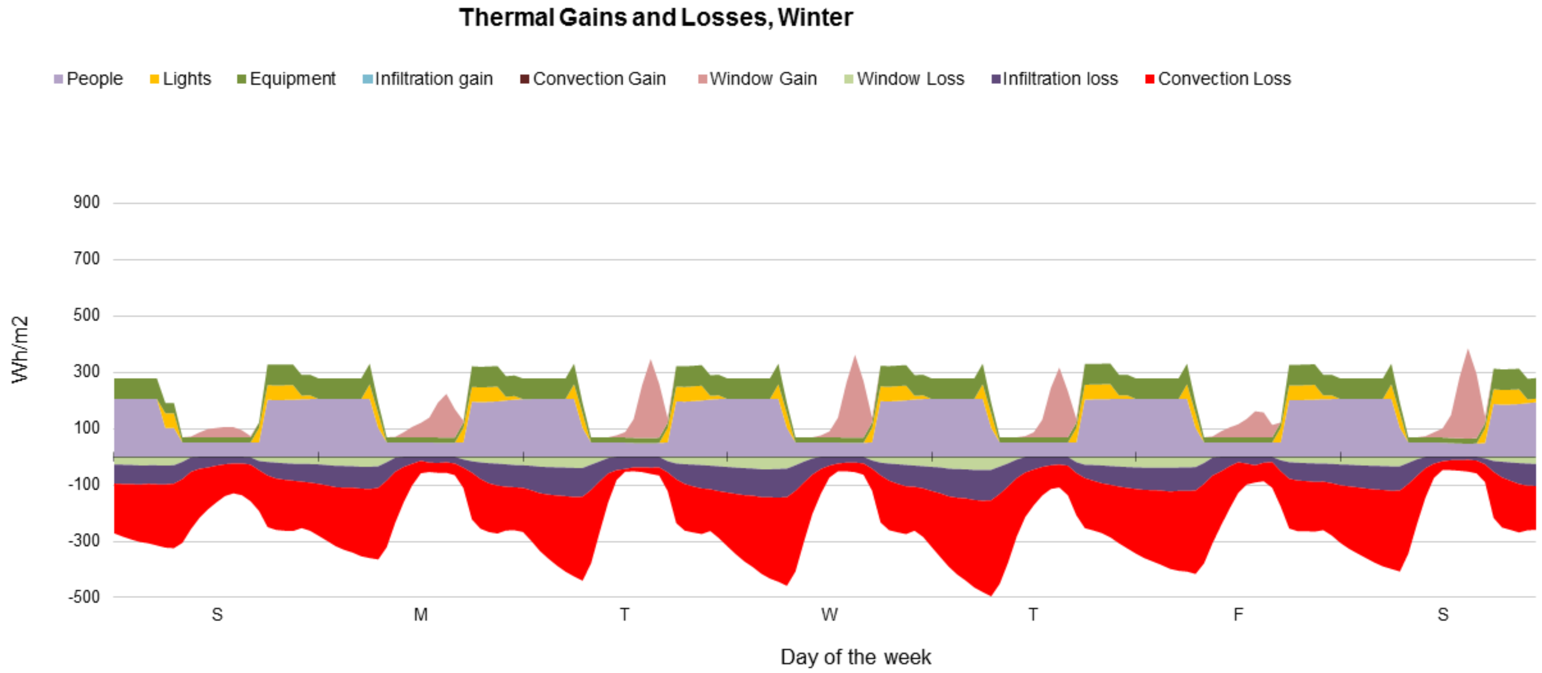

Figure 4.24 Rowhouse thermal gains and losses in winter

Source: Author

As can be seen in Figure 4.23 and Figure 4.24 respectively, there are numerous factors which contribute towards the thermal comfort of any given space. As explained in section 4.5.1, the range of data is based on weather, orientation, structural components, building usage and occupancy, and other internal loads. By analysing a summer week and a winter week, it is apparent which contributors are consistent, which are seasonal, and which can be altered to improve comfort.

In the summer months, the peaks formed by window gains for rowhouses are due to the excessive amount of solar radiation which comes through during the day. This could be due to a host of reasons: poor building orientation, window position, sun glare, lack of shading devices or reflective coatings, glazing specifications. An effective measure against high solar radiation, which would level the peaks, is the addition of shading devices to regulate the change in temperature between the outside air and inside air during summer. Shading devices do not have to be mechanical; they could even be in the form of an indigenous, deciduous tree which delivers effective shade relative to the seasons.

Another observation for rowhouses in summer, are their relatively high convection gains during the day, which are seemingly self-countered each day by the convection losses in the evening. While these convection gains and losses seem to be roughly equal, a useful addition would be ceilings and insulation to prevent the unnecessary loss of heat in the evenings, or gain during the day. Windows and doors can be used to regulate temperature here by opening and closing them as necessary (provided that they are air-tight when closed).

The occupancy rates within rowhouses plays a large role in contributing to the heat gains of the space. Usually, spaces are more comfortable if there are less people per square metre. However, with regards to the rowhouses, fewer members per household may actually have a negative impact on the thermal comfort within the space, as this would mean less body heat keeping the small spaces warm on colder winter evenings.

Compared to summer, the rowhouse performs far worse on winter evenings. This is primarily attributed to the high convection losses in the evenings, which could be solved by changing the type of wall from an un-plastered 220mm thick brick wall to a (preferably plastered) double brick cavity wall to allow for added insulation, or by adding sufficient insulation or cladding to existing walls.

People occupancy loads remain a high contributor to internal heat gains, which is surprisingly welcome in the winter months, even though the spaces might be congested. Thermal comfort is subjective here, as it is dictated by the season and individual user. A more sustainable occupancy rate might translate to colder inhabitants due to there not being enough people to generate heat to warm the space. However, this would mean that there would be more available space per person.

The other gains and losses are negligible in comparison to the ones mentioned, so will not be discussed further.

4.5.1.2 Maisonette thermal gains

This thermal gains graph was generated using the East facing bedroom in the northern flat on the top floor.

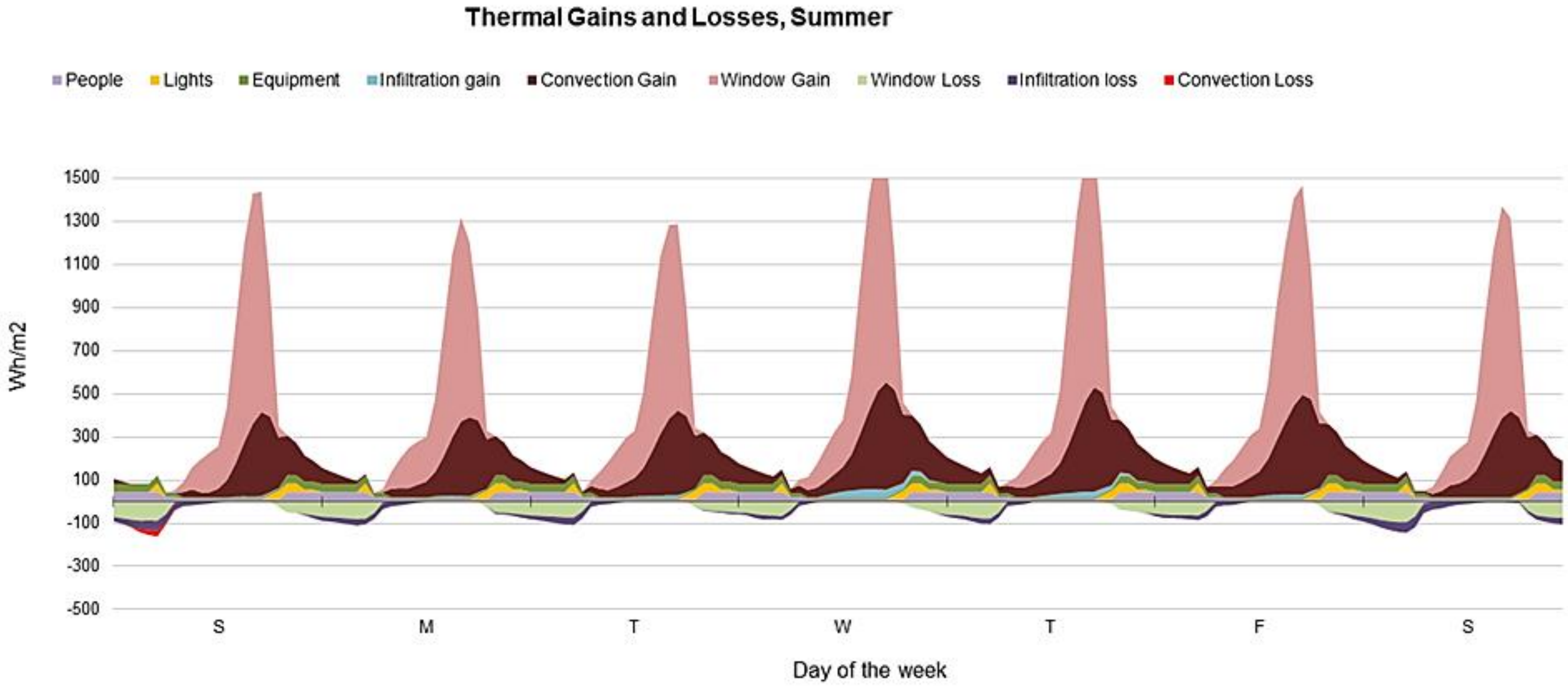

Figure 4.25 Maisonette thermal gains and losses in summer

Source: Author

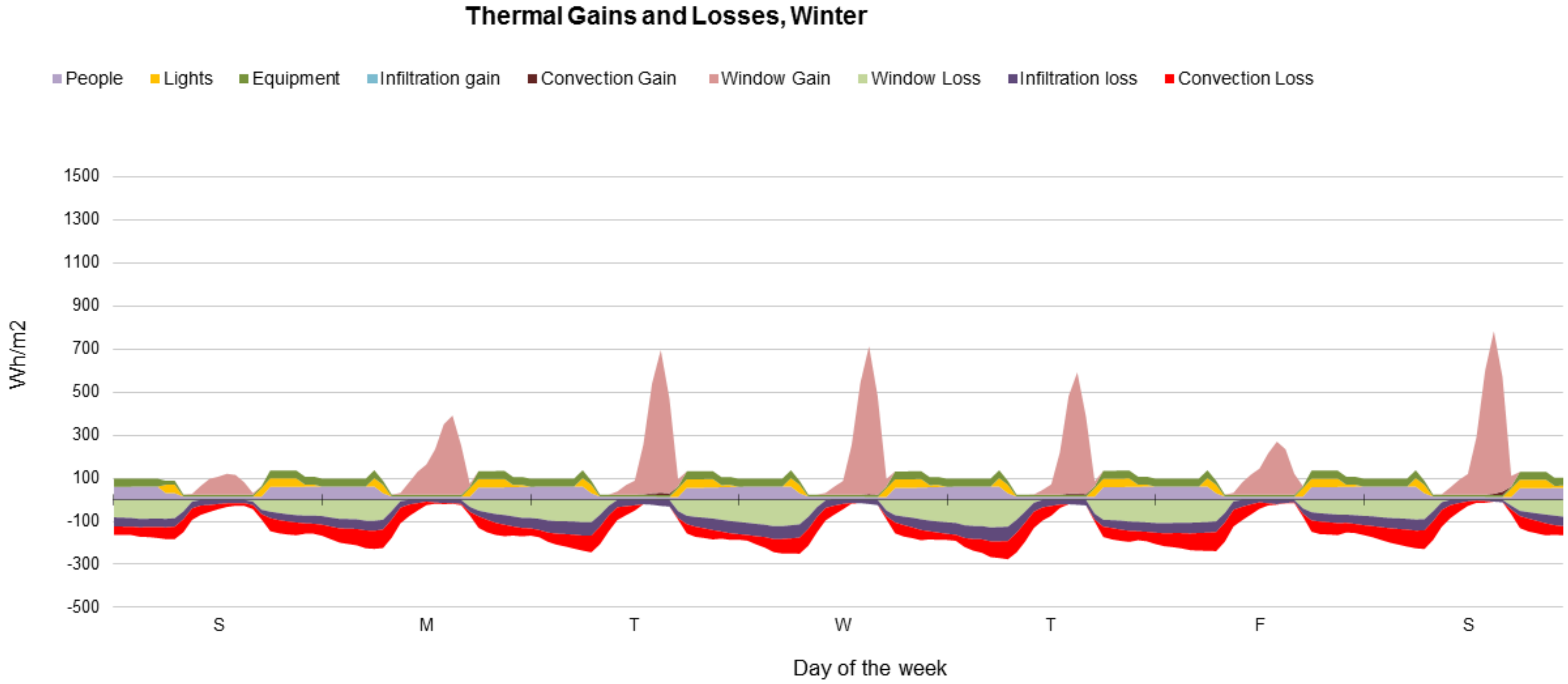

Figure 4.26 Maisonette thermal gains and losses in winter

Source: Author

In summer, the maisonette's window gains are highly noticeable. It is depicted by the large pink areas. This type of building attracts a large amount of heat through conduction and solar radiation, especially during the hot summer days. This creates peaks in thermal discomfort as there is negligible roof overhang and no shading devices in place to remedy this. It would therefore be advisable that in summer, these peaks are reduced by incorporating interventions such as roof overhangs and shading devices.

A similarly large gain worth preparing for in the summer months is that of convection gain. This heat, generated from walls and roofs, can be adjusted with the use of insulation.

Despite the large heat gains in summer, the winter months only see the occasional pink peaks associated with window gains. Efforts to change the current single-glazed windows to double-glazed windows may reduce the peaks associated with conductance in summer, but would reduce the solar radiation in winter as well, which might make the space colder, and is also expensive to install.

Optimally placing windows, with appropriately angled shading devices could regulate the winter radiation (as is necessary). While shading devices are useful in any almost any form in summer, their size and angle becomes of utmost importance to ensuring that useful winter radiation is not obstructed.

4.5.1.3 Cottages thermal gains

This thermal gains graph was generated using measurements from a west facing bedroom in the northern flat.

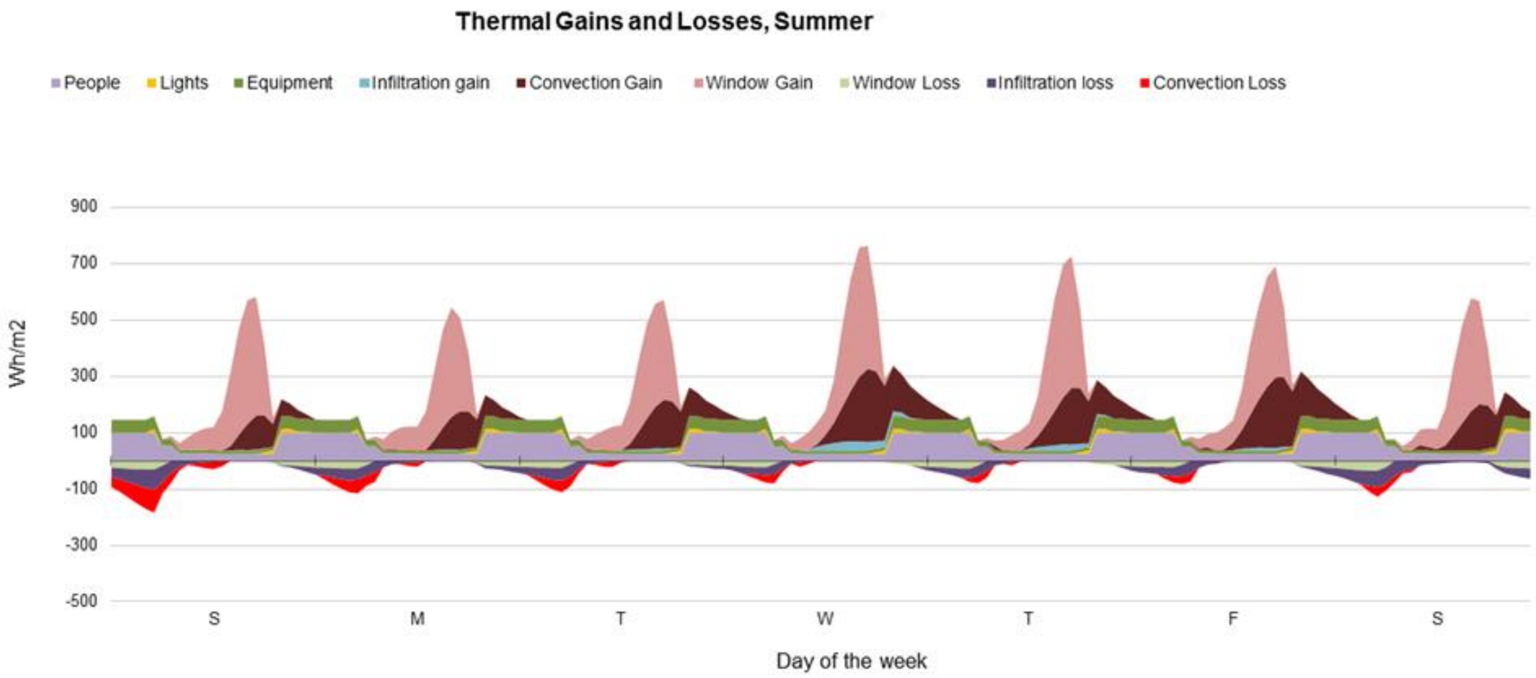

Figure 4.27 Cottages thermal gains and losses in summer

Source: Author

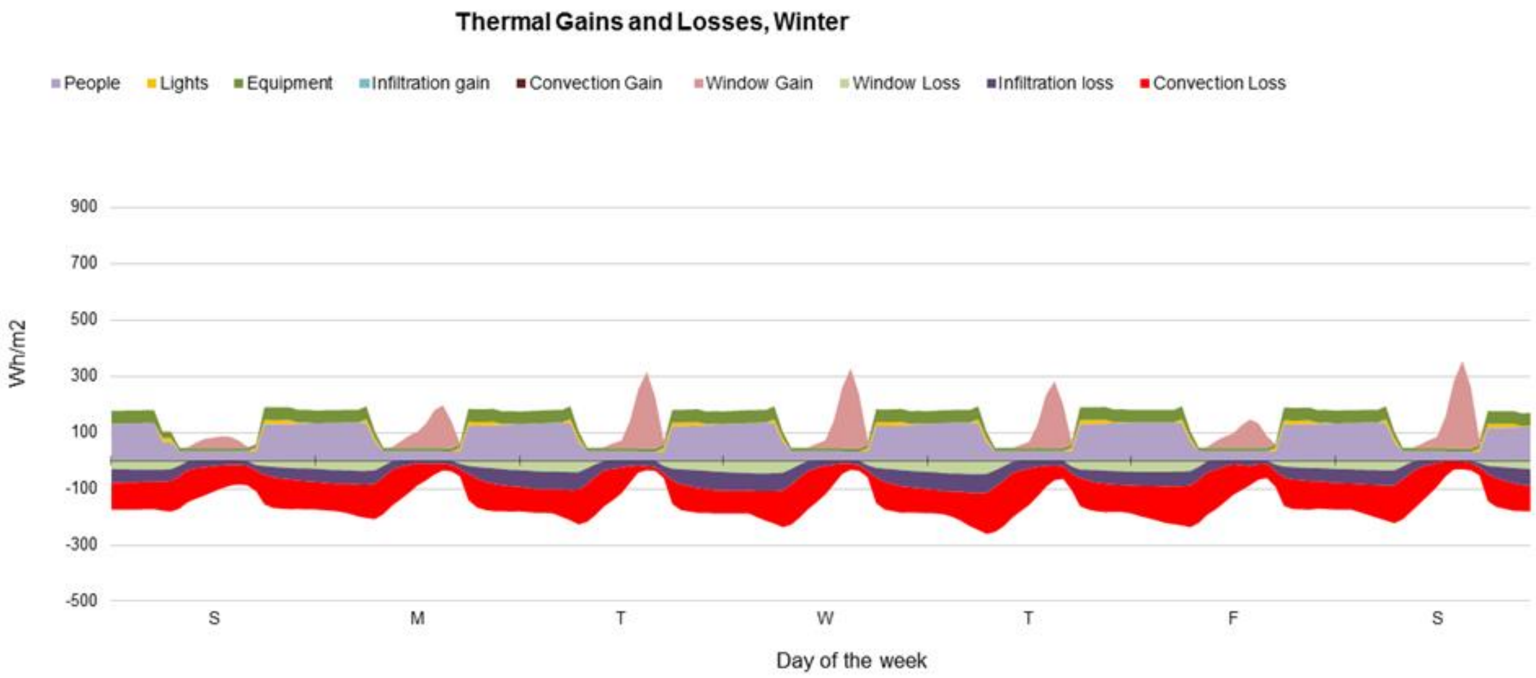

Figure 4.28 Cottages thermal gains and losses in winter

Source: Author

As with the rowhouses mentioned in 4.5.1.1 and the maisonettes in 4.5.1.2, the highest heat gain for the cottages is recorded from the windows. Window heat gains in summer days are countered by the infiltration and convection losses in the evenings. The cottages are quite cool in summer, compared to rowhouses and maisonettes. The other gains are negligible compared to the window gains.

While not heating up is a positive attribute for summer, the cottages perform poorly in winter as a result. During the winter months, there are no significant heat gains during the day, but high convection losses are consistent throughout the year. As the walls and roof are seemingly thermally inefficient, it would be advisable that these components be renovated with better thermal insulation.

4.5.1.4 Courts thermal gains

This thermal gains graph was generated using a west facing bedroom on the second northern flat on the top floor.

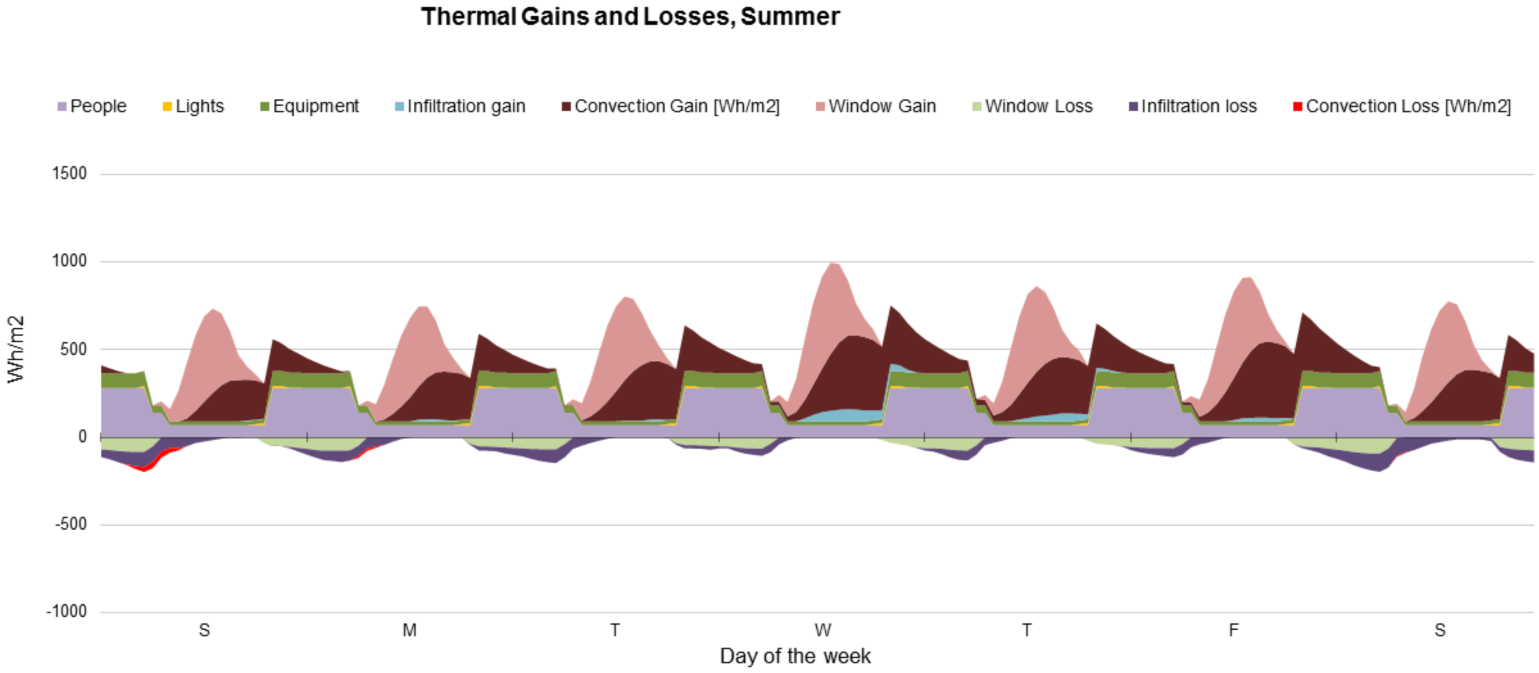

Figure 4.29 Courts thermal gains and losses in summer

Source: Author

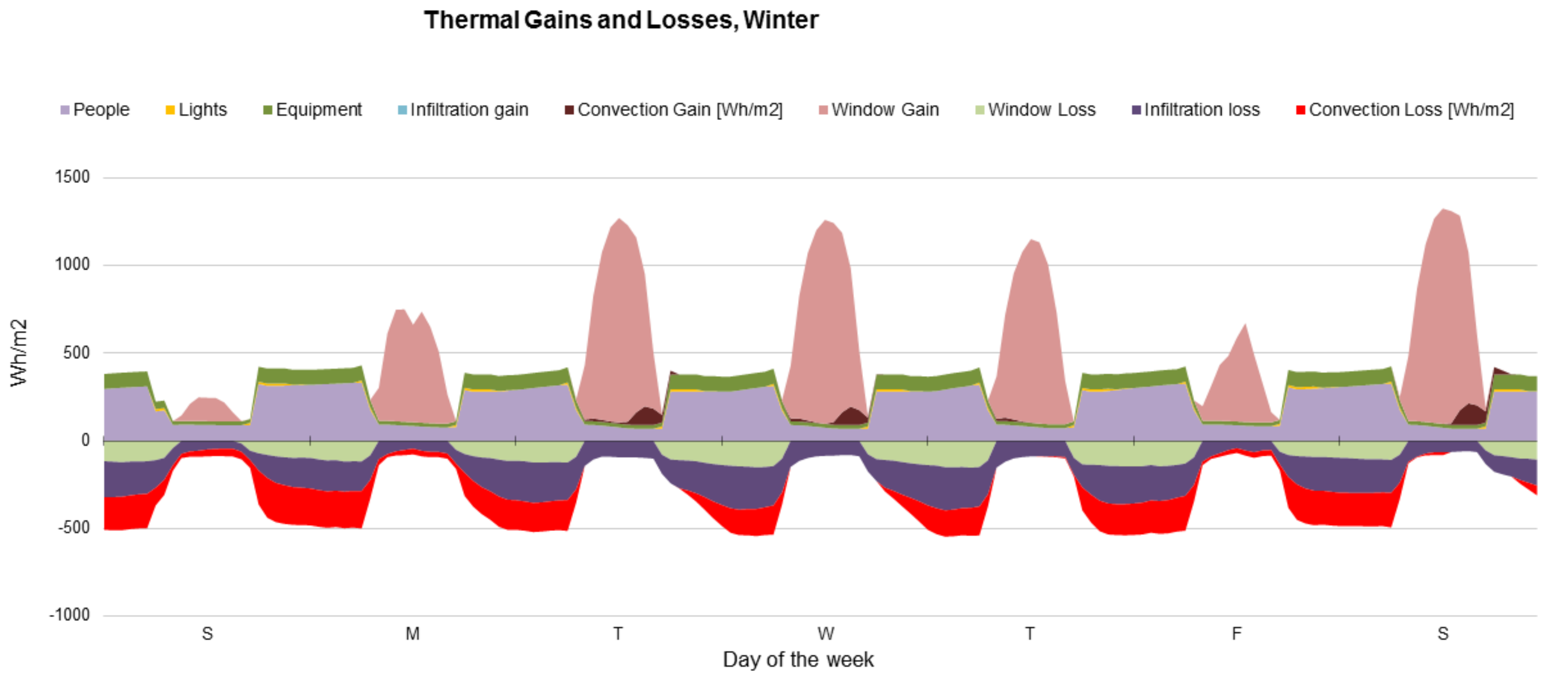

Figure 4.30 Courts thermal gains and losses in winter

Source: Author

As can be observed in Figure 4.29, the courts are quite warm in summer due a host of different factors: heat is generated by the tenants, there are gains throughout the day through the walls and roof, and morning peaks through the windows. While infiltration gains are small, they are still noticeable. It can also be observed here that there are minimal heat losses throughout the day, which means that the heat remains trapped inside. Based on these summer results, it might prove useful to insulate the walls and the roof, and to install well-positioned shading devices, that would be able to thwart excessive summer solar radiation, but that would retain vitally important winter solar radiation.

Figure 4.30 demonstrates that the courts are thermally inefficient because they are hot in summer, and equally cold in winter. These buildings have high window peak gains which are useful in terms of solar radiation, but almost no other heat gains due to the building structure. The high thermal losses (through the walls, roof, and windows, and through infiltration) mean that almost none of the heat generated through the windows in the mornings is retained. People are the only other dependable source of heat. However, this occupancy is unsustainable because it can contribute to factors such as spatial discomfort and poor hygiene.

In order to reduce the high losses during winter, the use of brick cavity walls, insulated walls and roofs and better floor coverings is recommended.

4.5.1.5 Government Reconstruction and Development Programme house thermal gains

This thermal gains graph was generated using west facing bedroom.

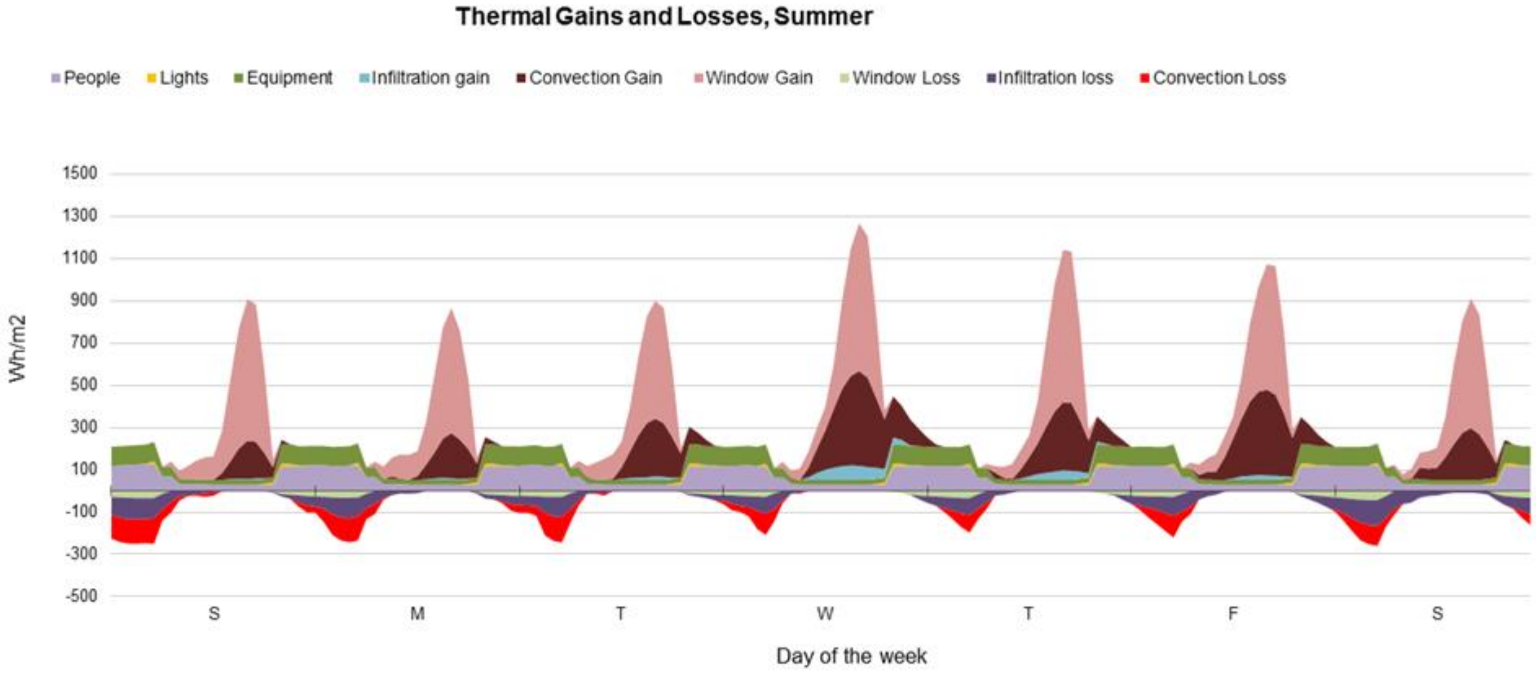

Figure 4.31 Government Reconstruction and Development Programme house thermal gains and losses in summer

Source: Author

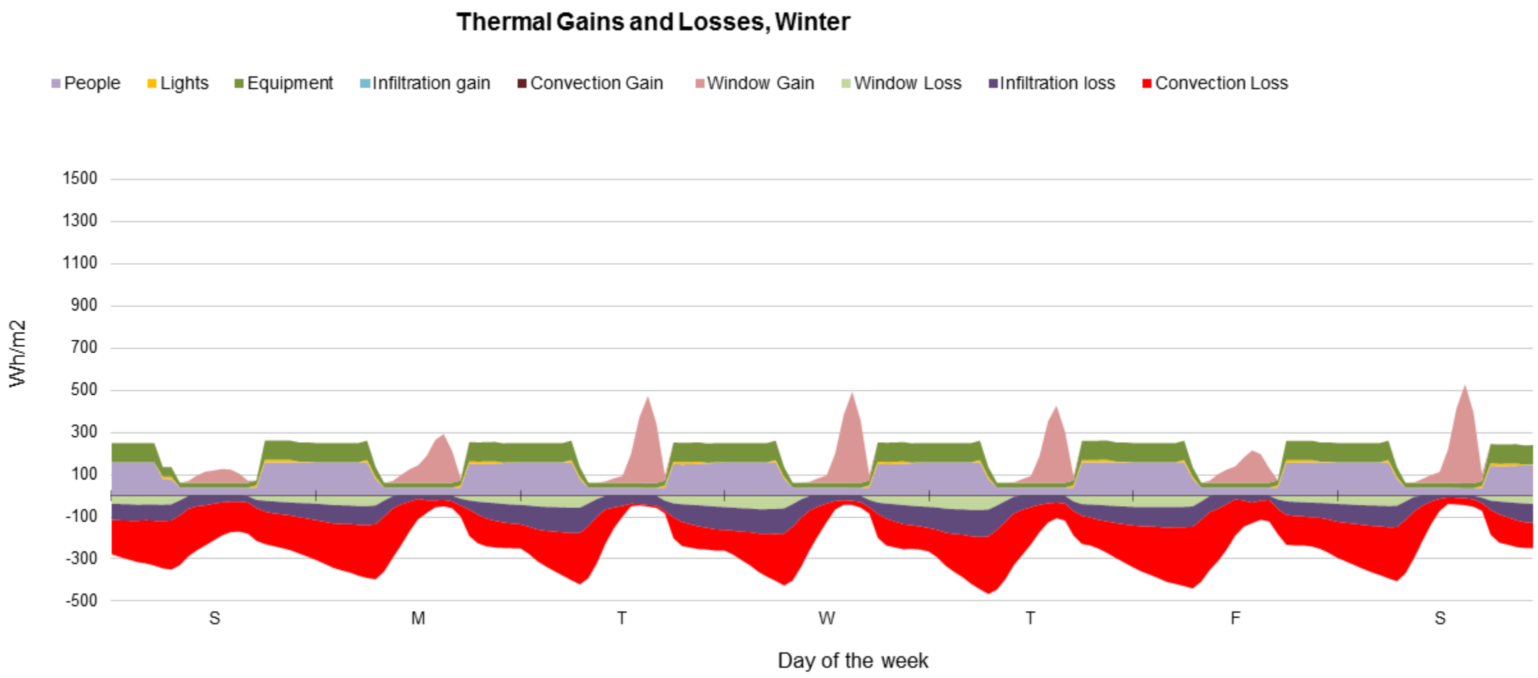

Figure 4.32 Government Reconstruction and Development Programme house thermal gains and losses in winter

Source: Author

In summer, the government subsidised Reconstruction and Development Programme (RDP) houses heat up quite a lot due to window gains, as can be seen from the very high peaks, Occasionally, the peaks seen in Figure 4.31 are associated with convection gains as well, but these are irregular.
The combination of window heat gains and convection heat gain has produced a noticeable infiltration heat gain which suggests that the outside air temperature is higher than the inside.

Despite the high gains in summer, the Reconstruction and Development Programme houses are actually quite cool in winter due to the high convection losses in the evenings. These losses are due to the fact that the houses have no ceilings, as well as the poor insulation value of the walls. As suggested for the Courts in section 4.5.1.4, shading devices need to be designed carefully in order not to eliminate useful winter solar radiation.

To make the space more thermally comfortable, i.e. cool in summer and warm in winter, it may be useful to change the current single brick construction to double brick cavity walls. As well as this, well positioned awnings, the installation of insulated ceilings and properly sized roof overhangs would assist in regulating temperature throughout the year.

4.5.1.6 Migrant labour hostel (1-storey) (MLH1) thermal gains

This thermal gains graph was generated using a west facing room.

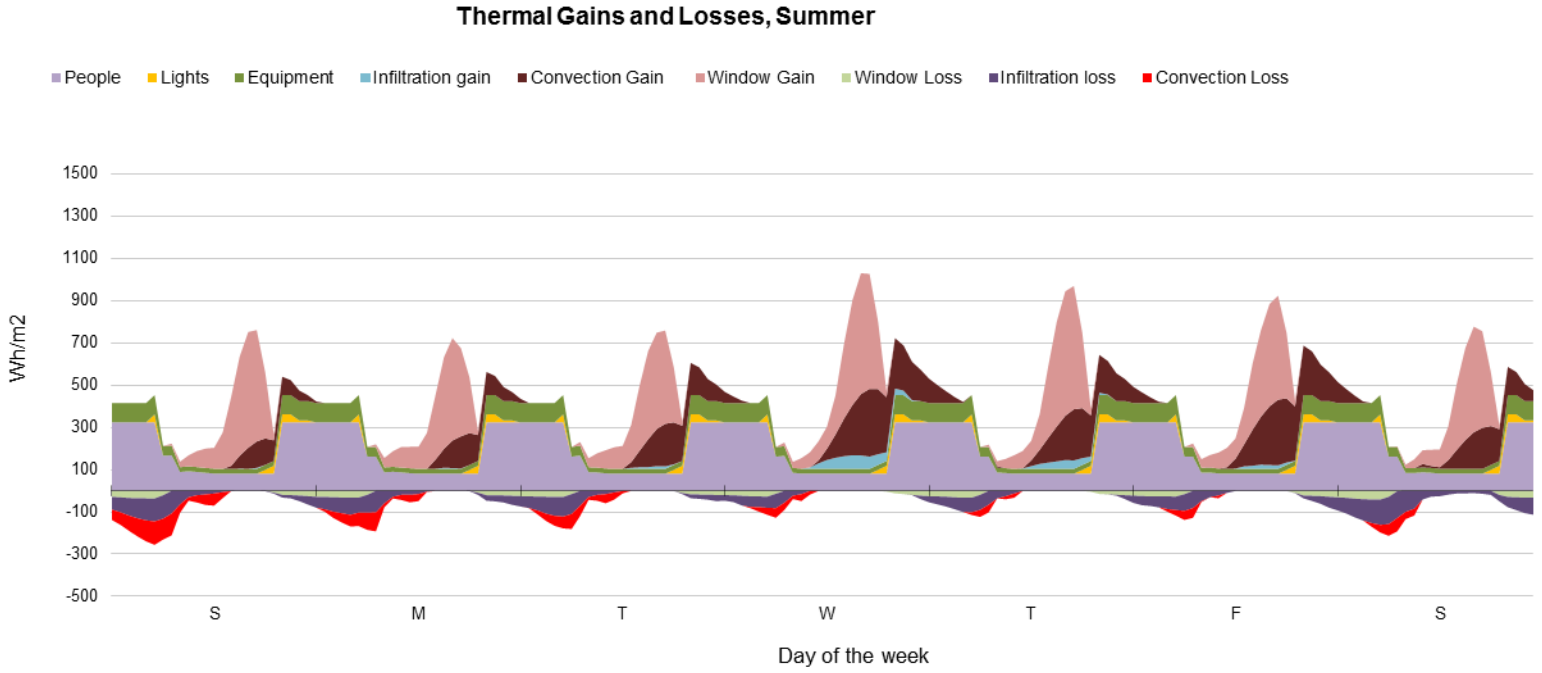

Figure 4.33 MLH1 thermal gains and losses in summer

Source: Author

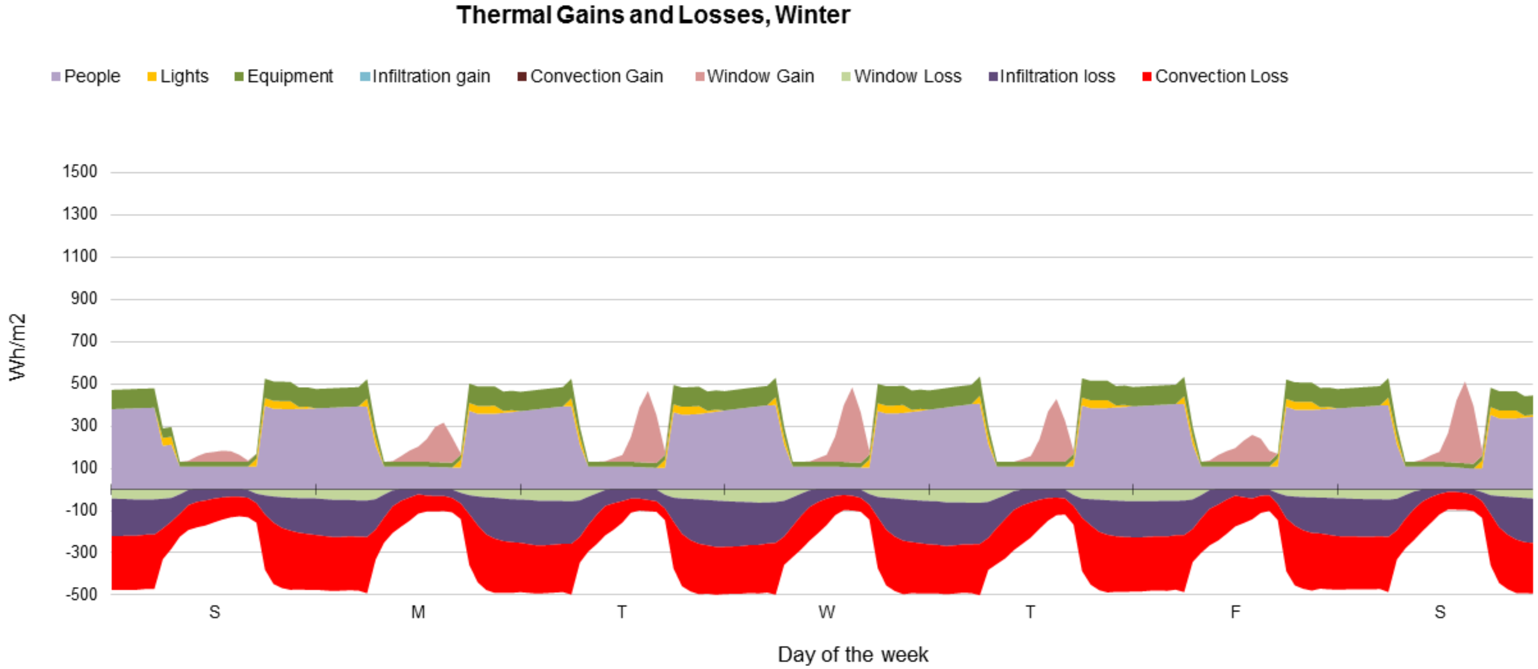

Figure 4.34 MLH1 thermal gains and losses in winter

Source: Author

Figure 4.33 illustrates how overcrowded the single storey migrant labour hostels are, with people occupancy contributing the most to heat gains in summer. While this generation of heat might be welcome in winter months, it makes it more difficult to effectively cool the space using only passive design measures (such as natural ventilation). Lowering occupancy rates (number of people per room) might make it more comfortable. That being said, the only heat gain in winter is through people occupancy, and if bigger rooms were to be provided for smaller groups of people, the heat generated from body heat would no longer be enough to keep the occupants (relatively) warm in winter.

The high convection and window gains in the summer months result in peaks which only contribute to the discomfort of the resident during the warmer seasons. This is compounded by the fact that the air does not seem to cool down in the evenings, as daytime gains are not balanced with evening losses.

As can be observed from the graphs, the hostels are one of the most thermally inefficient buildings thus far. As hot as it is in summer, the heat losses in winter due to convection and infiltration make the space even colder. Well-placed shading devices would help more than building insulation, as in summer months, you actually want the heat to disperse effectively.

4.5.1.7 Migrant labour hostel (2-storey) (MLH2) thermal gains

This thermal gains graph was generated using a west-facing bedroom in the north of the top floor.

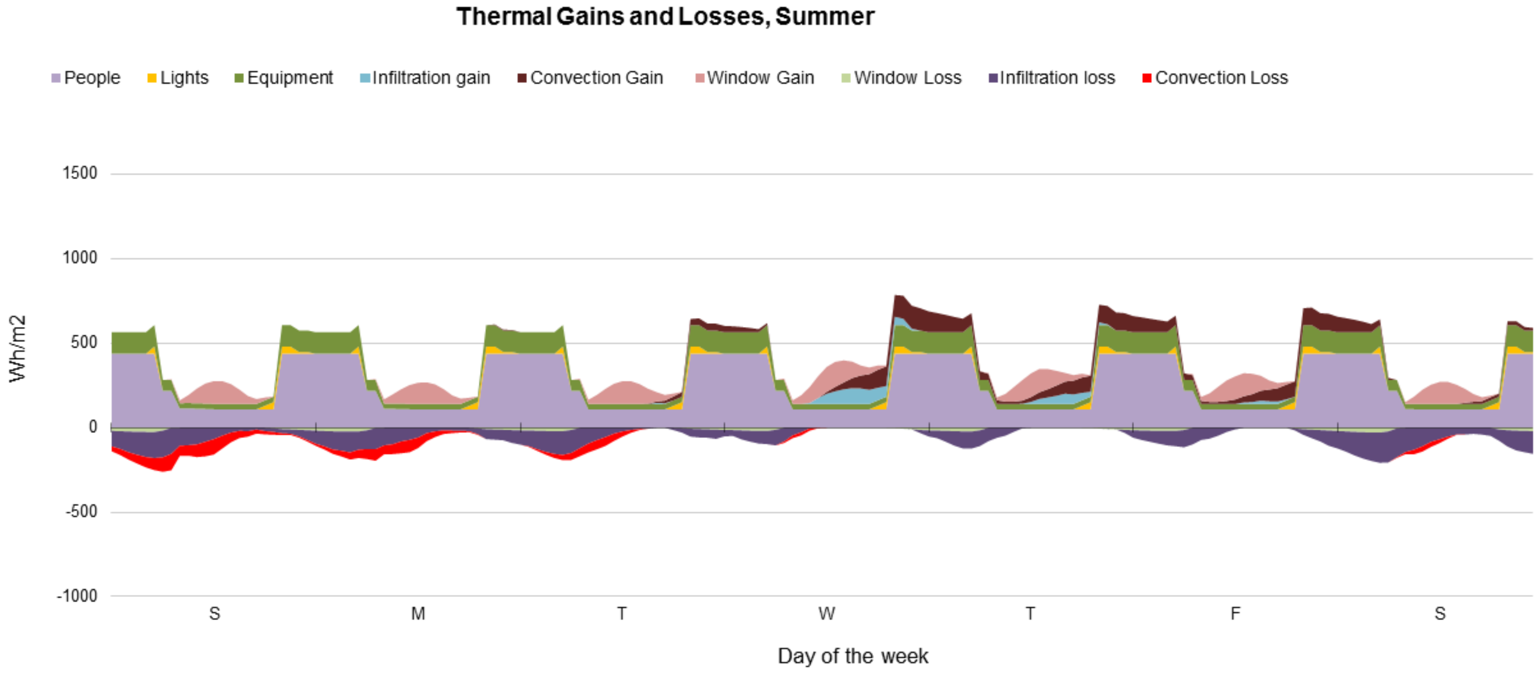

Figure 4.35 MLH2 thermal gains and losses in summer

Source: Author

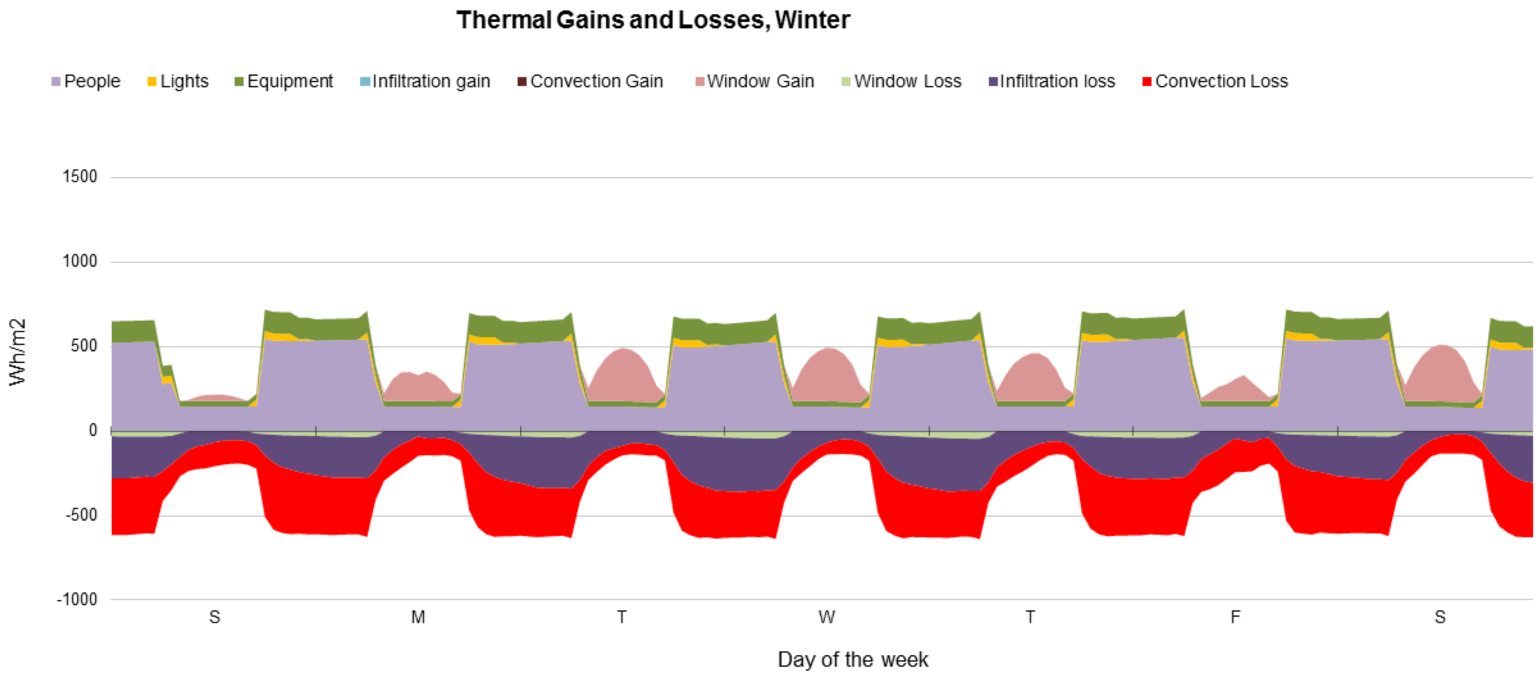

Figure 4.36 MLH2 thermal gains and losses in winter

Source: Author

As with the single storey migrant labour hostels mentioned in 4.5.1.6, observations from the graph in 0 indicate that occupancy loads in the two storey migrant labour hostels play an equally large role. In summer, the number of people per room is arguably the only source of heat, which could imply that the rooms are relatively comfortable. However, occupancy gains are also the only relatively significant heat gain in winter, which means that the hostels remain cold during the colder months. There is also a minimal amount of heat generated from the windows on winter mornings.

Another reason for the cold hostel rooms is the high convection and infiltration losses throughout the day in winter. This could be addressed by insulating the walls, roofs and windows, and by switching to floor coverings which have better insulation properties, as well as adding ceilings.

4.5.1.8 ‘2-storey’ thermal gains

This thermal gains graph was generated using west facing bedroom in the northern flat on the top floor.

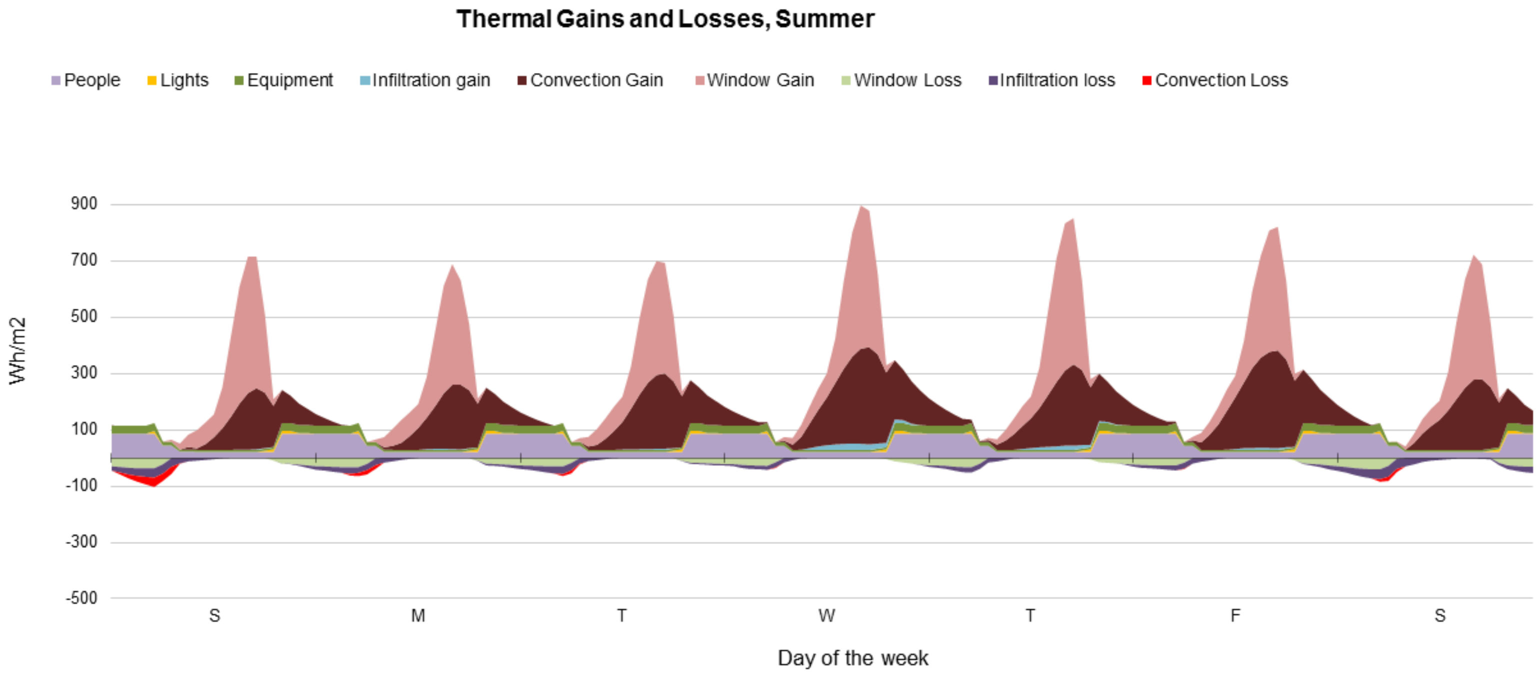

Figure 4.37 ‘2-storey’ thermal gains and losses in summer

Source: Author

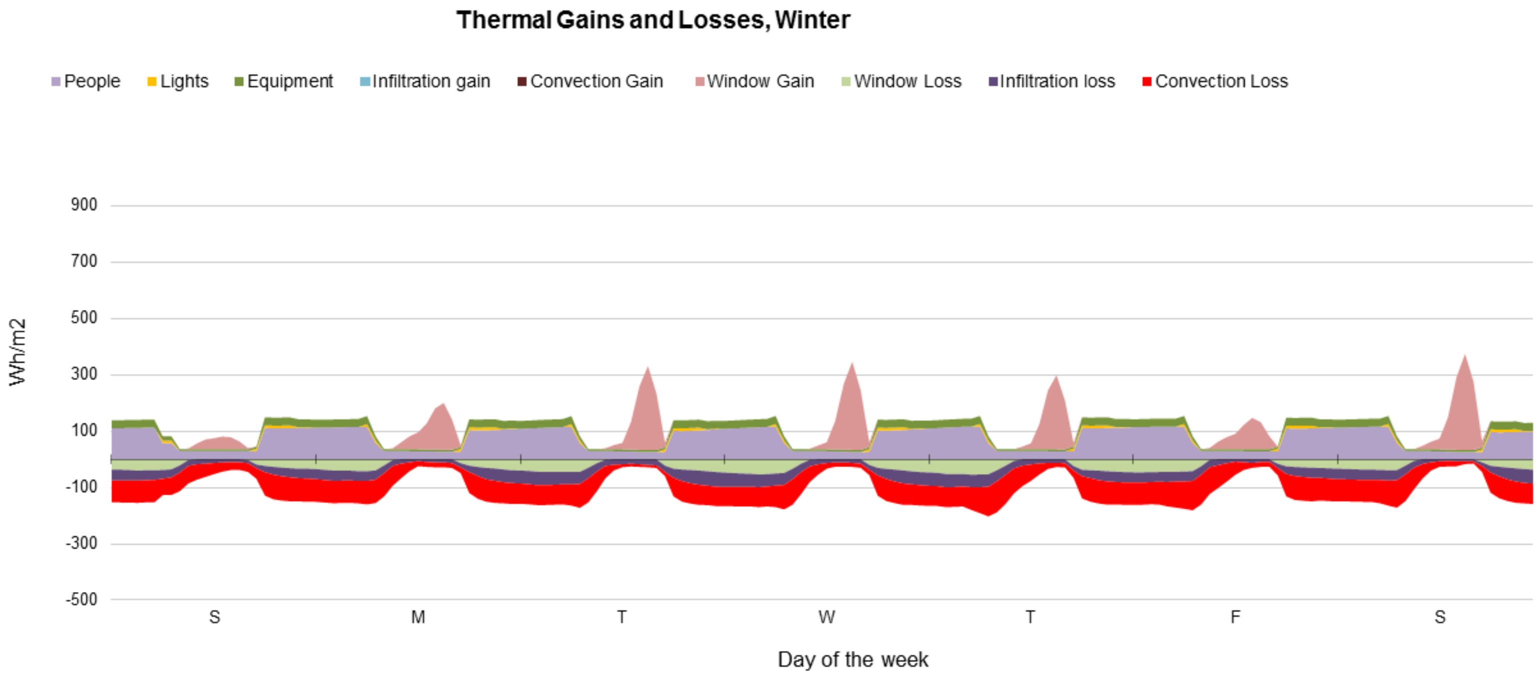

Figure 4.38 ‘2-storey’ thermal gains and losses in winter

Source: Author

The ‘2-storeys’ are characterised by very high window gain peaks, as in the case of most of the other building types mentioned earlier (rowhouses in 4.5.1.1, maisonettes in 4.5.1.2, cottages in 4.5.1.3 and the government Reconstruction and Development Programme houses in4.5.1.5). As we have learnt in 4.3.8, the ‘2-storey’ buildings have high occupancy loads. However, comparatively, the window and convection gains dominate the heat contribution. This results in very hot rooms in summer, with no relief in the evenings or through the day by way of heat losses. Painting the roof white, as well as insulating it and optimally placing shading devices on the windows, may cool the building down. It should be noted, too, that the asbestos roofs insulate better than sheeted roofs, but are not significantly different in terms of their insulation value. Regardless, these should be replaced at all costs, as they are a serious health hazard to tenants.

As hot as the summer months were, the winters are cold. As can be observed in 4.5.1.8, there are no heat gains worth mentioning, and the losses balance them out as they stand. While the peaks from the window gains could be remedied, it is not advisable, as they are one of the only forms of heat. In order to combat the heat losses, the building should be better insulated, and ceilings added. Floors and roofs should be upgraded to ones with better insulating properties.

4.6 Summary

This section presents the results of the analyses according to the objectives which they aimed to achieve. Gugulethu and Manenberg were selected as the two most representative townships based on a predetermined set of criteria. The second stage of analysis revealed eleven common types of buildings found, of which nine formal building types were analysed further. These were the rowhouses; maisonettes; cottages; courts; government Reconstruction and Development Programme houses; the two types of migrant labour hostels; and the ‘2-storey’ building. In order to determine how much energy is used by each type of building, energy modelling studies were completed using Designbuilder. From these models, it was also possible to extract thermal gains graphs in order to better ascertain how comfortable the spaces are throughout the year, where energy was being wasted, and to provide research-informed insights on ways in which to improve building design in order for them to become energy efficient. The typologies were presented according to their consumption profiles. The last chapter discusses the key findings and recommendations for future work based on this, and earlier chapters in the study.

5 Conclusions and Recommendations

This study presented insights into the benefit of examining the energy consumption of buildings within townships in the City of Cape Town, in order to understand the city's inclusive urban metabolism. It has suggested that an African city's context cannot be simulated based on typologies generated with data from countries of the Global North. This chapter indicates how the research results are linked to the literature review and proceeds to describe how the study might contribute to practice.

The primary research aim of the study was to build a typology of low-cost buildings with regards to their energy profile. In order to achieve this, the following research objectives were addressed:

i. To classify representative low-cost building types in selected representative townships within the City of Cape Town
ii. To examine energy consumption of the representative low-cost building types in the selected representative townships
iii. To develop typologies of representative low-cost building types based on their energy profile in the selected representative townships
iv. To determine the limitations of conventional and alternative energy systems within the low-cost building sector in the City of Cape Town

These objectives were met within the scope of the study, by utilising methods such as literature review, typology building, energy modelling, and semi-structured interviews, as described in section 3. This section offers a summary of key findings, the limitations of the study, highlights areas for improvement, and recommendations for improvement of energy efficiency approaches within township architecture using typologies of buildings.

5.1 Key findings

The literature on Africa's urbanisation reveals that the continent's population is growing rapidly. This urbanisation process is different to the western models of urbanisation, and as such needs to be addressed uniquely. Instead of mega-cities, there is a surge of smaller secondary cities that represent all scales of development. The way in which these cities metabolise implies a need for an incremental approach to dealing with their varied and interconnected challenges, and a careful and context-specific study of their respective resource profiles. It especially calls for a sustainable transition in the built environment, for which energy efficiency plays an important role. To this end, building rating systems, policies and institutional programmes play a vital role in understanding, implementing, regulating, and incentivising this transition. The low-cost building sector in the City of Cape Town has received some traction with the development of projects such as those mentioned in section 2.9, the Kuyasa CDM Project and the Joe Slovo Housing Development. However, these are still the exception, and not yet the rule. It is often a surprise to the city's citizens that the solar water heaters and new township architecture visible on the edges of the N2 highway only stretch as far as is visible to the middle and upper income group drivers on their way towards the airport, and is not yet commonplace throughout the 46 suburbs which 'qualified' as townships from my investigation. As such, the struggles of townships residents remain out of sight and muted, while the city works instead to appease those who are not directly affected. The memory of Apartheid is still embedded in the infrastructure and design of the City of Cape Town's townships. The lack of data for buildings in these townships limits future work in the area, which reinforces the neglect and abandonment that has been imposed on them thus far. As a result, a key recommendation of this study is to develop this data, and to make it publicly available. This typology study has been a step towards addressing this issue. The study objective was to build a typology of low-cost buildings, with regard to the energy profile, by filling the gap in knowledge and data regarding these building types and their related energy consumption within townships of the City of Cape Town, in order to understand the city's inclusive urban metabolism.

This study of the City of Cape Town revealed that more than half of the City of Cape Town townships are further than 20 kilometres away from the city's central business district, while 89% of them are still racially segregated, with over 65% of their population being of a single race (either Black or Coloured). The average resident within these townships still belongs to households which earn below the poverty line. Almost half of the townships around the City of Cape Town were built after Apartheid.

Gugulethu and Manenberg were the two representative townships of the City of Cape Town that were identified for further investigation. This study classified the following building types in the two representative townships: rowhouse buildings; maisonettes; cottages; courts; government Reconstruction and Development Programme houses; two types of migrant labour hostels and the '2-storey' buildings. While the study initially attempted to develop typology for all formal buildings within townships, it was later limited to the prominent but varied council homes. This was because the researcher did not want to generalise the other buildings types, which, while relevant to the energy landscape, cannot be categorised into individual typologies based on their energy profiles, due to their diversity. The private residential buildings, for example, come in hundreds of designs, and similar types have very irregular occupancy and behavioural profiles, which was found to impact heavily on the energy profiles.

A curious feature in the urban design of the City of Cape Town's townships is the forced north-south axis, which informs the orientation of the buildings within them to a large extent. A high percentage of them were found to have bigger east and west facing façades due to the layout of the streets, which negatively affected the amount of energy required to heat their homes. This was especially true in Manenberg, where almost all the council homes were orientated this way. There is still some diversity in Gugulethu. However, with its rows and rows of units, exposure of walls per unit to the sun is still limited, and therefore they are often quite cold.

The results of the energy profile simulations revealed a peculiarity: some of the buildings such as rowhouses, migrant labour hostels and courts were found to be thermally comfortable in winter, in spite of the dilapidated state of their structures. On closer investigation, it became apparent that this was due to the high occupancy rates within the building, which, while warm, are by no means comfortable. The buildings with the highest occupancy rates were the migrant labour hostels in Gugulethu. The courts and '2-storey' buildings in Manenberg followed closely. Despite almost all the houses having illegally constructed and electrified backyard units, space remains an issue within the formal buildings.

In terms of building construction, uninsulated and unplastered brick and concrete blocks remain the popular material choice for walls, with asbestos still dominating the roof material of all Apartheid-era buildings. While asbestos is potentially a better insulating material than the current alternative of corrugated iron sheeting, it is a health hazard. While not a part of the study, many of the residents complained of their children and grandchildren having chronic breathing ailments. Another issue with these buildings is that almost none of them have ceilings – this is a common trait throughout buildings constructed during Apartheid, and after. While there have been retrofitting projects completed in both townships, ceilings are still to be included in these. This is an example of the lack of research-informed interventions which have been delivered by the government, which fail to address the real living challenges faced by the residents. For example, in the courts buildings, new door handles, wiring, a fresh coat of paint, and a large electric hot water urn per unit were installed, none of which have been deemed useful by the residents. The buildings are still cold, because of poor (if any) insulation, no ceilings, no plaster on the walls, self-provided internal doors which barely fit their frames (if these were even provided), and windows which let more air into the building than they keep out. Despite efforts by the new Breaking New Ground model, especially under the new energy efficiency standards for new construction, to construct low income homes with ceilings and similar insulating measures, these homes are not yet widespread and were not a common typology in the two selected townships at the time of study.

Airtightness or a lack thereof, is also a large contributing barrier to energy efficiency within these buildings. Due to the violent activity in the neighbourhoods, and age of the buildings, the windows are often broken or cracked. As well as this, the original homes were not fitted with frames for external doors or with any doors internally. As there is an oft-awkward gap between the doors and the building opening, it was difficult for tenants to fit frames that could effectively close the gaps. This results in a lot of the hot air which might be gained through the day, being lost. The lack of internal doors and constricting placement of walls reduces the possibility for natural cross ventilation, leaving living spaces dark and often quite cold.

Many of the households use kettles for all their domestic hot water requirements, including bathing, washing, and cooking. This results in high electricity costs. Those who have geysers are not educated on efficient energy saving methods and as such, spend a large portion of their income on electricity consumed by geysers. Large electric urns provided by government take a long time to heat up and do not provide enough water for all their needs. Furthermore, they take up a lot of valuable space.

While many of the buildings were found to have transitioned towards energy efficient lighting, especially in Manenberg, the users of buildings in Gugulethu could still benefit from changing their bulbs. Lights are usually kept burning the entire day, therefore it could result in a decent saving if less watts were used.

Although appliance-based electricity surveys were conducted, it was difficult to compare this information across building types, due to differing energy consumption profiles. Some of the most commonly used appliances in townships; however, are televisions, radios and phone chargers. In Manenberg, most households had light-emitting diode (LED) TVs, while in Gugulethu, they were still using the older Cathode Ray Tube (CRT) TVs which, use more electricity. While most households also have fridges and microwaves, almost everyone interviewed admitted to keeping their fridges on the lowest settings, which often made the food go off. Most interviewees hardly ever used their microwaves, except for one interviewee in Gugulethu's single storey hostel unit who did not have a kettle, and preferred to use an electric urn to boil a large quantity of water in the morning for the day, and then use her microwave for the remaining smaller hot water needs. Many residents also made use of either two-plate stoves or gas stoves instead of electric hobs, as they cooked throughout the day. Most ladies in Manenberg also admitted to using hair dryers and straighteners every day!

From the thermal gains graphs, it was found that the majority of building types are thermally inefficient. This means that they remain hot indoors in summer, and are cold in winter. The biggest contributors to this thermal inefficiency is the air leakage from openings, the overheating from lack of shading elements (roof overhangs, awnings, window shading devices), poor insulating capacity of walls, floors and roofs, and occupancy loads. Lights and equipment played negligible roles in thermal comfort.

It is recommended that new projects and policies take into consideration the findings of this study and similar studies, and *contextual* analyses to design new buildings with the *correct* orientation (i.e. building plans which optimise access to natural light on the northern and eastern façades); and also retrofit existing buildings by doing the following:

i. Incorporate ceilings in the designs;
ii. Provide wall insulation;

iii. Plaster the walls;
iv. Use lightweight materials where possible;
v. Design in a way that allows for customisation and expansion;
vi. Where required, offer reflective roof materials and provide well-placed shading elements such as awnings and roof overhangs;
vii. Conduct airtightness tests;
viii. Consider the number of people and joint-family lifestyles of the communities when designing nuclear units;
ix. Offer solar water heaters and rooftop PV;
x. Replace incandescent lighting with energy efficient lighting, in order to move buildings from the higher consumption groups to lower ones, while remaining thermally comfortable at the same time.

5.2 Self-assessment

Although the researcher initially set out to complete the study within one year, it became apparent that townships (and the study thereof) are not as straightforward and accessible as other parts of Cape Town might be. While it was possible to study literature in a timely fashion, access to the identified townships, and to data pertaining to them, was an entirely different matter. Therefore, in order for the study to be thorough and relevant, more time was necessary. The non-linearity of the research process allowed for reinterpretation of old information which led to a constantly evolving study. If it were not for the desire to meet the graduation deadline, this research would probably carry on, with new information materialising each day. Concluding the research was a challenge because every bit of new information seemed as important as the last, and as though it should be included in the study. Initially, the researcher was under the impression that a purely quantitative analysis of township buildings would be sufficient to profile their energy consumption and to offer suggestions. However, hardly any relevant building design information was available from online sources, or the municipality. This created a problem which might have been easily solved by accessing the sites directly. However, there were long periods of instability in one of the selected townships, and it was advised that the researcher wait it out for safety reasons. The first-hand information from site visits to each of the building types and discussions with inhabitants was beneficial for more than just information on building construction. It led to a more fulfilling research experience for the researcher, and a better study overall, because data correlated to the real-world experience of the building user. As has been identified in the results section, and remarked on again in this chapter, the lack of communication between the people who build in townships, and the people who use the buildings, has a direct and visible impact on the disconnect between what the users need and what the buildings offer, which often results in a waste of energy.

5.3 Limitations of the study

Access to data

There were two limitations to gaining access to data. The first was that there were no official plans made available by the municipalities for the identified township building types. Architects had plans, but only for newly constructed social housing projects, which are mostly located on the highly visible edges of the N2 Highway, and which are not *yet* representative of *common* building types across all townships in Cape Town. In order to remedy this scarcity of official data, it was necessary to access sites directly to gather data on the ground. This brings us to the second limitation. As with any low income group, the issues preventing these townships from overcoming the limits of poverty and related social constructs such as race, social class, drug use, political and economic structures, and power, are interconnected, complex, and hardly straightforward. Manenberg is in the heart of the notorious Cape Flats, a region drowning in gang culture. In order to access the sites here, gang shootings needed to be monitored, especially during the course of 2015 and early 2016 (the period of research), when gang activity was intensified.

To gather building information necessary for developing energy models (documented in Table 3.2 and Table 3.3), the researcher was required to spend time on site measuring spaces, observing and taking photographs to determine material and construction properties of each building, as official data was insufficient or unverified. A lot of the measuring of buildings was done before visiting the townships, using measuring tools such as Google Earth Pro and scaling using images from online sources, books, or peer reviewed articles, and then verified in person.

Energy modelling data

Even though the research period was extended, certain aspects of the energy modelling process were rushed due to the time taken to obtain data initially. This may have had an effect on the quality of data, although it does not invalidate the research. While the data limited the exact replication of the actual buildings, they were sufficiently representative in terms of their thermal properties and sizing. In energy modelling, it is more important to allocate materials which have the correct thermal properties, regardless of what the material actually might be; and to ensure that the window to wall area ratio is respected, regardless of the precise positioning of the window. For example, if the thermal properties can be conveyed, it does not matter if the material assigned to the model is specifically concrete, or a duplicate with similar properties to concrete. This being said, the researcher did try to build models as accurately as possible, with regards to the expected outputs. Another limitation of time on the energy modelling process pertained to the generation of the thermal gains graphs. For these graphs, an educated guess on a representative building zone was taken, supported by a built environment industry professional. This meant that only one zone (or room) of each building was analysed, for two weeks in a year – one week in the middle of summer, and one week in the middle of winter. Given more time, the researcher would suggest that more, or all, the zones within each building type are studied, and for longer periods of time.

Sample size

As there were no official datasets available to validate the data through triangulation, it is recognised that the size of the samples could have been improved. There were three levels of sampling which took place, the first in townships. While all township data was analysed in order to select two representative ones, it may be useful in future to choose more townships, or townships that collectively cover a wider geographical region. Gugulethu and Manenberg are across a railway line from one another. Sampling in this manner might result in a more diverse building stock, but was not tested in this study.

The second level involved sampling the different types of buildings within the selected townships. Currently, eleven building types were identified, of which eight were evaluated and categorised, most of which were rental council homes of varying ages. Initially, one of the sub-objectives of the study was to determine the prominence of a building type by counting how many times the building appeared in the photography database from site visits. However, these databases were limited to photographs of buildings that the researcher had captured and the researcher was not able to go through all of the streets, which meant that not all the buildings in the townships were captured. To rectify this, Google Earth Pro was again utilised to identify buildings from the zones which the researcher could either not access, or did not access due to a lack of time. Residents were also useful in identifying common building types in their communities which had not previously been noted, or which were noted but categorised incorrectly. Although the required number of buildings was sampled, a bigger sample may have allowed for the study of more building types. For example, private residential houses and bigger mixed use buildings, as well as electrified shacks and backyard dwellings were not included in the study. These buildings could not be categorised due to their vast diversity in design. Related to this, the amount of energy used by inhabitants of illegal dwellings attached to formally serviced buildings was not investigated; instead, this consumption was grouped with that of the formal buildings. However, it could be argued that these additions are a part of almost all township buildings these days, due to increased urbanisation and need for shelter.

The third level of sampling was related to the participants of the study. The researcher was limited in terms of the residents of each community that could be interviewed regarding their homes and energy consumption behaviours. One of the reasons for this is that many residents were living illegally on property, or were not paying for electricity, which made them hesitant to take part in the study. The researcher was also sometimes seen as an outsider, which was a limitation because of the type of information residents were willing to divulge. The residents who were identified were very welcoming, but the other residents they identified were mostly friends or family. Therefore, while the sample was diverse in terms of the types of buildings the interviewees occupied, it was not random. It may be useful in future to send an open invitation to the community to participate in surveys, rather than to visit people in their homes. However, these visits were vitally important for enhancing and verifying data.

Interviews and questionnaires

Due to the informality of the space within which residents were approached, the nature of questioning needed to be adjusted. Even though a detailed set of questions had been mapped out, the *in situ* approach was to invite a broad overview of the residents' personal experience with regards to the buildings they occupied, and then to prompt them appropriately to garner detailed information. Premeditated questions were mostly related to energy consumption behaviour. Initially it was hoped that the questionnaires could be given out ahead of time to be completed before the visits, but in order to accommodate the residents, and their varying levels of education and comfort in filling out forms, it was necessary for the researcher to fill in the questionnaires herself while at the residents' homes. Residents were initially hesitant to divulge their consumption behaviours, but were prompted by the researcher through on-site observations regarding thermal comfort and the types of appliances which were visible. The first few residents were initially shy, but later visits achieved more detailed breakdowns. Previous responses often informed the questions posed to the next building user, in order to make the process faster. The limitations presented by i) the improvised style of questioning and recording, ii) the lack of preparedness in the responses of the building users (although the researcher is not entirely convinced this is a real limitation as it may have contributed towards the robustness of the users' responses), and iii) hesitation of community members to take part in the study, could be overcome by a future study which considers allocating more time to the research and enables the researcher to become embedded within the community.

5.4 Recommendations for future work

The key findings and limitations identified by the researcher open up avenues for future work in this area of study.

Data scarcity

There is currently limited data pertaining to the energy profiles of existing township buildings. This is because there is little official documentation and poor record-keeping of designs, plans and construction drawings for these buildings, and townships in general. Future work could consider compiling this data throughout townships in Cape Town and making this data available to the public. Instead of merely drawing up buildings from observation, it would be useful for proper time and funding to be spent on measuring the buildings and documenting their building properties. This process will provide sound, scalable datasets that are verified by local authorities, from which context-based retrofitting projects could be done.

Contextual design interventions

Results of current retrofit projects, and even some of the buildings energy modelling iteration results, prove that interventions that are made without consideration for context do not improve existing conditions. Certain retrofits do not add any value to thermal comfort or to the reduction of energy waste. Case studies may assist in this regard, as well as researchers being embedded within the areas of study to help communities to open up to them. These contextual, research-informed approaches will allow for design interventions that can effectively minimise energy waste.

Quantifying informal energy use

This study modelled formal township buildings in order to determine their energy use (and waste), but there is a considerable portion of this energy which is attributed to informal buildings within townships. There is a common misconception that shacks and backyard dwellings do not get electrified. This however, is not true. At the moment, it is a challenge to model the energy consumption of informal buildings because of the illegal electrical connections and construction of the structures. However, so many *backyarders* consume energy from the formal buildings whose sites they are constructed on. Future studies should firstly determine the degree to which informal buildings are electrified and consume energy in proportion to the formal built environment, and secondly, consider how to quantify the energy consumed formally, and that which is channelled informally.

Modelling the urban metabolism of City of Cape Town

Combining the energy data produced in this study; the energy data derived from the proposed quantification of informal energy use; and other energy data from existing formal and more readily available sources, would result in a more accurate representation of the energy flows coming into and out of the City of Cape Town. Even if only the total energy flow is calculated and modelled, it would go a long way towards modelling the entire urban metabolism of the city. A more advanced study might look at the entire urban metabolism, using similarly compounded data sets for each of the relevant flows.

Additional typologies based on the concept of 'suppressed demand'

The concept of suppressed demand, which was not previously referred to in this study, but which may provide a useful foundation, refers to situations where the services provided are insufficient due to a variety of situations out of communities' control, such as poverty or lack of access to energy infrastructure. Based on this understanding, which is relevant to the profiles of many buildings within township or low-cost settings, the existing data sets and building category definitions could be extended to include a profile of suppressed demand. Typologies could be generated which are more representative than conventional energy consumption graphs that were utilised in older studies.

Combine different forms of energy profiling

In this study, three different types of energy information were gathered per type of building; however, it was a challenge to combine this information. For example, the profiling done through the practical appliance usage was not correlated to the results of the energy modelling. The third type of energy information, by way of the thermal gains, was useful to interpret and correlate the energy modelling data and experiential data. It would be useful to find a way to combine these three types, and perhaps other forms of energy modelling, to produce a single holistic output.

There are many more possibilities for future work in this area. The growing rate of urbanisation threatens to overcrowd townships even further. The need for the low-cost built environment to expand is greater now than it ever was. However, this growth goes hand in hand with higher resource use, specifically energy. In order to provide for the future, it is clear that existing buildings and future projects need to consider how to become more energy efficient. To do so, public and private entities would need to become more transparent regarding the types of data available, and to develop the existing data in order to encourage research-backed policies and projects which can lead to an alternative model of township construction which is conducive to sustainable development.

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Appendix A: Suburb Profiles

2011 Census City Of Cape Town Suburb Profiles		Town-ship	Racial composition	Residential monthly income	Year of formation	Notes
1	*Acacia Park*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		
2	*Athlone*		Mixed Race	0-40% earn R3200 or less		
3	*Atlantis Non Urban*		Mixed Race	41-50% earn R3200 or less		51%C 28%W; 50% earn poor monthly income
4	*Atlantis*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		85%C; 50% earn poor monthly income; formal and informal dwellings present
5	*Belhar*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		90%C; 35% earn poor monthly income
6	*Belville Non Urban*		Mixed Race	0-40% earn R3200 or less		56%C 24%W
7	*Bellville Park*		Mixed Race	0-40% earn R3200 or less		47%W 25%B
8	*Bellville*		Majority White			
9	*Bellville South*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		88%C; 37% earn poor monthly income
10	*Bellville Teachers Training College*					Non residential
11	*Bergvliet*		Majority White			

12	*Bishop Lavis*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		92%C; 47% earn poor monthly income; formal and informal dwellings present
13	*Bishopscourt*		Majority White			
14	*Blackheath*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		82%C; 40% earn poor monthly income
15	*Bloekombos*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1998	89%B; 80% earn poor monthly income; formal and informal dwellings present
16	*Bloubergstrand*		Majority White			
17	*Blue Downs*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		77%C; 48% earn poor monthly income; formal and informal dwellings present
18	*Bonteheuwel*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1960s	94%C; 52% earn poor monthly income; formal and informal dwellings present
19	*Bothasig*		Majority White			
20	*Brackenfell*		Majority White			
21	*Brooklyn*		Mixed Race	0-40% earn R3200 or less		36%B 32%C 30%W
22	*Camps Bay*		Majority White			
23	*Cape Peninsula National Park*					Non residential
24	*Cape Town CBD*		Mixed Race	0-40% earn		

				R3200 or less		
25	*Cape Town International Airport*					Non residential
26	*Capri*		Majority White			
27	*Capricorn*		Mixed Race	0-40% earn R3200 or less		
28	*Castle Rock*		Mixed Race	0-40% earn R3200 or less		50%B 46%C
29	*Century City*		Mixed Race	0-40% earn R3200 or less		
30	*Claremont*		Majority White			
31	*Clifton*		Majority White			
32	*Clovelly*		Majority White			
33	*Coniston Park*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		93%C; 33% poor monthly income
34	*Constantia*		Majority White			
35	*Crossroads*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1987	97%B; 81% earn poor monthly income; formal and informal dwellings present
36	*Croydon*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		74%C; 26% poor monthly income
37	*Da Gama Park*		Mixed Race	0-40% earn R3200 or less		
38	*Delft*	X	Mixed Race	51%-100% earn R3200	1989	52%B 46%C; 69% earn poor monthly

				or less		income; formal and informal dwellings present
39	*Diep River*		Majority White			
40	*Doornbach*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		99%B; 94% earn poor monthly income; formal and informal dwellings present
41	*Dreyersdal*		Majority White			
42	*Dunoon*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1996	90%B; 77% earn poor monthly income; formal and informal dwellings present
43	*Durbanville*		Majority White			
44	*Edgemead*		Majority White			
45	*Eersterivier*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		79%C; 30% earn poor monthly income
46	*Elsies River*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		89%C; 50% earn poor monthly income; formal and informal dwellings present
47	*Epping Industria*					Non residential
48	*Erinvale Golf Estate*		Majority White			
49	*Eversdal*		Majority White			
50	*Fairways*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		78%C; 19% earn poor monthly income
51	*Firgrove*		Mono-racial (65% Black	0-40% earn R3200 or		91%C; 34% earn poor monthly income

			OR Coloured)	less		
52	*Firgrove Rural*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		65%B; 21% earn poor monthly income
53	*Fisantekraal*	X	Mixed Race	51%-100% earn R3200 or less		52%B 47%C; 73% earn poor monthly income; formal and informal dwellings present
54	*Fish Hoek*		Majority White			
55	*Foreshore*					Non residential
56	*Freedom Park Airport*	X	Mixed Race	51%-100% earn R3200 or less		63%B; 91% earn poor monthly income; formal (very few, almost neglible) and informal dwellings present
57	*Gardens*		Majority White			91%C; 34% earn poor monthly income
58	*Glencairn*		Majority White			91%C; 34% earn poor monthly income
59	*Goodwood*		Mixed Race	0-40% earn R3200 or less		44%W 32%C
60	*Gordons Bay*		Majority White			91%C; 34% earn poor monthly income
61	*Grassy Park*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		88%C; 32% earn poor monthly income
62	*Green Point*		Mixed Race	0-40% earn R3200 or less		62%W
63	*Gugulethu*	X	Mono-racial (Black OR Coloured)	51%-100% earn R3200 or less	1958	99%B; 71% earn poor monthly income; formal and informal dwellings present
64	*Hanover Park*	X	Mono-racial	51%-100%		94%C; 58% earn

			(65% Black OR Coloured)	earn R3200 or less		poor monthly income; formal and informal dwellings present
65	*Hazendal*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		93%C; 54% earn poor monthly income; formal and informal dwellings present
66	*Heathfield*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		71%C; 27% earn poor monthly income
67	*Heideveld*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		92%C; 47% earn poor monthly income; formal and informal dwellings present
68	*Helderburg Small Holdings*		Mixed Race	0-40% earn R3200 or less		
69	*Hout Bay*		Mixed Race	0-40% earn R3200 or less		56%W 33%C
70	*Imizamo Yethu*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1990s	92%B; 79% earn poor monthly income; formal and informal dwellings present
71	*Joe Slovo Park*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		95%C; 73% earn poor monthly income; formal and informal dwellings present
72	*Kalk Bay*		Mixed Race	0-40% earn R3200 or less		55%W 32%C
73	*Kenilworth*		Mixed Race	0-40% earn R3200 or less		54%W 21%B 16%C

74	*Kenridge*		Majority White			71%C; 27% earn poor monthly income
75	*Kensington*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		91%C; 33% earn poor monthly income
76	*Khayelitsha*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1983	99%B; 74% earn poor monthly income; formal and informal dwellings present
77	*Killarney Gardens*					Non residential
78	*Kirstenhof*		Majority White			
79	*Kleine Zout Rivier Small Holdings*	X	Mixed Race	51%-100% earn R3200 or less		57%C 28%W; formal and informal dwellings present
80	*Klipheuwel*	X	Mixed Race	51%-100% earn R3200 or less		54%B 39%C; formal and informal dwellings present
81	*Knole Park*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		82%C; 63% earn poor monthly income; formal and informal dwellings present
82	*Kommetjie*		Majority White			
83	*Kraaifontein*		Mixed Race	0-40% earn R3200 or less		46%W 42%C
84	*Kraaifontein Small Holdings*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		76%B; 79% earn poor monthly income; formal and informal dwellings present
85	*Kuils River*		Mixed Race	0-40% earn R3200 or less		20%W 19%B 58%C
86	*Kuils River Small Holdings*	X	Mono-racial (65% Black	40-50% earn R3200 or		65%C; 49% earn poor monthly

			OR Coloured)	less		income; formal and informal dwellings present
87	*Lakeside*		Majority White			
88	*Langa*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1990	99%B; 72% earn poor monthly income; formal and informal dwellings present
89	*Lansdowne*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		66%C; 24% earn poor monthly income
90	*Lavender Hill*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		95%C; 59% earn poor monthly income; formal and informal dwellings present
91	*Llandudno*		Majority White			65%C; 49% earn poor monthly income
92	*Lotus River*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		93%C; 40% earn poor monthly income
93	*Macassar*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		89%C; 50% earn poor monthly income; formal and informal dwellings present
94	*Maitland Garden Village*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		88%C; 38% earn poor monthly income
95	*Maitland*		Mixed Race	0-40% earn R3200 or less		50%C 42%B
96	*Mamre*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		95%C; 49% earn poor monthly income; formal and informal dwellings present

97	*Manenberg*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1966	85%C; 61% earn poor monthly income; formal and informal dwellings present
98	*Marconi Beam*					Non residential
99	*Marina da Gama*		Majority White			
100	*Masiphumelele*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1995	91%C; 82% earn poor monthly income; formal and informal dwellings present
101	*Meadowridge*		Majority White			
102	*Melkbosstrand*		Majority White			
103	*Mfuleni*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1999	96%B; 77% earn poor monthly income; formal and informal dwellings present
104	*Milnerton Non Urban*		Mixed Race	0-40% earn R3200 or less		38%B 38%W
105	*Milnerton*		Majority White			
106	*Mitchells Plain*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		91%C; 38% earn poor monthly income
107	*Montague Gardens*					Non residential
108	*Monte Vista*		Majority White			
109	*Montevideo*		Mixed Race	0-40% earn R3200 or less		59%B 38%C
110	*Morning Star Small Holdings*		Majority White			
111	*Mowbray*		Mixed Race	0-40% earn		44%B 36%W

				R3200 or less		
112	*Muizenberg*		Mixed Race	0-40% earn R3200 or less		50%W 23%B 18%C
113	*Ndabeni*	X	Mixed Race	51%-100% earn R3200 or less	1901	49%B 36%C; 51% earn poor monthly income; formal and informal dwellings present
114	*Newlands*		Majority White			
115	*Noordhoek*		Majority White			
116	*Nyanga*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less	1946	99%B; 74% earn poor monthly income; formal and informal dwellings present
117	*Observatory*		Mixed Race	0-40% earn R3200 or less		40%B 34%W
118	*Ocean View*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		91%C; 48% earn poor monthly income; formal and informal dwellings present
119	*Oranjezicht*		Majority White			
120	*Ottery*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		72%C; 20% earn poor monthly income
121	*Oude Molen Village*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		75%B; 80% earn poor monthly income; formal and informal dwellings present
122	*Paarden Eiland*		Mixed Race	0-40% earn R3200 or		36%B 36%C; 0% earn poor monthly

				less		income
123	*Panorama*		Majority White			
124	*Parklands*		Mixed Race	0-40% earn R3200 or less		49%W 36%B; 13% earn poor monthly income
125	*Parkwood*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		97%C; 54% earn poor monthly income; formal and informal dwellings present
126	*Parow*		Mixed Race	0-40% earn R3200 or less		57%C 28%W
127	*Pelikan Park*		Mixed Race	0-40% earn R3200 or less		63%C; 40% earn poor monthly income
128	*Pella*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		97%C; 54% earn poor monthly income; formal and informal dwellings present
129	*Philadelphia*		Mixed Race	0-40% earn R3200 or less		59%C 34%W; 33% earn poor monthly income
130	*Philippi*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		94%B; 78% earn poor monthly income; formal and informal dwellings present
131	*Philippi Small Holdings*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		71%C; 59% earn poor monthly income; formal and informal dwellings present
132	*Phoenix*		Mixed Race	0-40% earn R3200 or less		56%B 36%C
133	*Pinelands*		Majority			

			White			
134	*Plattekloof*		Majority White			
135	*Plumstead*		Mixed Race	0-40% earn R3200 or less		55%W 29%C
136	*Pollsmoor*		Mixed Race	0-40% earn R3200 or less		48%C 45%B
137	*Red Hill*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		80%B; 83% earn poor monthly income; formal (very few, almost neglible) and informal dwellings present
138	*Retreat*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		87%C; 39% earn poor monthly income
139	*Richwood*		Majority White			
140	*Robben Island*		Mixed Race	0-40% earn R3200 or less		60%B; 25% earn poor monthly income
141	*Rondebosch/Rosebank*		Mixed Race	0-40% earn R3200 or less		56%W 24%B
142	*Rugby*		Mixed Race	0-40% earn R3200 or less		37%W 32%C 25%B
143	*Ruytewacht*		Mixed Race	0-40% earn R3200 or less		51%C 33%W
144	*Salt River*		Mixed Race	0-40% earn R3200 or less		45%C 40%B
145	*Scarborough*		Majority White			
146	*Schotschekloof*		Mono-racial (65% Black	0-40% earn R3200 or		66%C; 31% earn poor monthly income

			OR Coloured)	less		
147	*Scottsdene*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		90%C; 37% earn poor monthly income
148	*Sea Point*		Majority White			
149	*Sheraton Park*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		90%C; 43% earn poor monthly income; formal and informal dwellings present
150	*Silvermine*					Non residential
151	*Silvertown*	X	Mono-racial (65% Black OR Coloured)	41-50% earn R3200 or less		95%C; 43% earn poor monthly income; formal and informal dwellings present
152	*Simons Town*		Mixed Race	0-40% earn R3200 or less		56%W 31%B
153	*Sir Lowry's Pass*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		66%C; 63% earn poor monthly income; formal and informal dwellings present
154	*Somerset West Non Urban*		Mixed Race	0-40% earn R3200 or less		50%W 33%C
155	*Somerset West*		Majority White			
156	*Southfield*		Mixed Race	0-40% earn R3200 or less		31%W 53%C
157	*St James*		Majority White			
158	*Steenberg Estate*		Majority White			
159	*Steenberg*	X	Mono-racial (65% Black	51%-100% earn R3200		94%C; 53% earn poor monthly

			OR Coloured)	or less		income; formal and informal dwellings present
160	*Stikland Hospital*		Mixed Race	0-40% earn R3200 or less		56%B 24%C
161	*Stonehurst Mountain Estate*		Majority White			
162	*Strand*		Mixed Race	51%-100% earn R3200 or less		54%B 27%C 17%W; 58% earn poor monthly income
163	*Summer Greens*		Mixed Race	0-40% earn R3200 or less		53%B 29%C
164	*Sun Valley*		Majority White			
165	*Sunningdale*		Majority White			
166	*Sybrand Park*		Mixed Race	0-40% earn R3200 or less		57%C 18%W
167	*Table Mountain Nature Reserve*		Mixed Race	0-40% earn R3200 or less		0% earn poor monthly income
168	*Table View*		Majority White			
169	*Tamboerskloof*		Majority White			
170	*Thornton*		Mixed Race	0-40% earn R3200 or less		49%C 26%B
171	*Tijgerhof/Sanddrift*		Mixed Race	0-40% earn R3200 or less		61%W
172	*Tokai*		Majority White			
173	*Tygerberg Hospital*					Non residential
174	*University of Cape Town*					Non residential

175	*University of the Western Cape/Peninsula Technikon*		Mono-racial (65% Black OR Coloured)	0-40% earn R3200 or less		81%B; 0% earn poor monthly income
176	*V&A Waterfront*		Mixed Race	0-40% earn R3200 or less		40%B 27%W
177	*Vissershok*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		85%B; 93% earn poor monthly income; formal and informal dwellings present
178	*Vredehoek*		Majority White			
179	*Vrygrond*	X	Mixed Race	51%-100% earn R3200 or less		62%B; 77% earn poor monthly income; formal and informal dwellings present
180	*Wallacedene*	X	Mono-racial (65% Black OR Coloured)	51%-100% earn R3200 or less		80%B; 81% earn poor monthly income; formal and informal dwellings present
181	*Welgelegen*		Majority White			
182	*Welgemoed*		Majority White			
183	*Westlake*	X	Mixed Race	41-50% earn R3200 or less		50%B 26%C 21%W, formal and informal dwellings present
184	*Wingfield*		Mixed Race	0-40% earn R3200 or less		53%C 39%B
185	*Woodstock*		Mixed Race	0-40% earn R3200 or less		25%B 50%C 14%W
186	*Wynberg*		Mixed Race	0-40% earn R3200 or		21%B 46%C 24%W

				less		
187	*Youngsfield*		Mixed Race	0-40% earn R3200 or less		21%B 52%C 20%W
188	*Ysterplaat Airbase*		Mixed Race	0-40% earn R3200 or less		0% earn poor monthly income
189	*Zeekoei Vlei*		Mixed Race	0-40% earn R3200 or less		40%W 36%C
190	*Zonnebloem*		Mixed Race	0-40% earn R3200 or less		39%B 31%C 20%W

Appendix B-1: Buildings captured in Gugulethu

Photo	S, M, NR	Formality	Type
	Not Applicable	Formal	Non residential/public
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Not Applicable	Formal	Non residential/public
	Single	Formal	Private residential house
	Not Applicable	Informal	Non residential/public
	Not Applicable	Informal	Non residential/public
	Single	Formal	Rowhouse
	Single	Formal	Private residential house
	Single	Formal	Rowhouse

	Single	Formal	Rowhouse
	Single	Formal	Rowhouse
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Rowhouse
	Single	Formal	Rowhouse
	Single	Mixed	
	Multi-family	Informal	Informal dwelling/shack
	Single	Informal	Informal dwelling/shack
	Multi-family	Informal	Informal dwelling/shack

	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Formal	Migrant Labour Hostel
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Rowhouse
	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Mixed	Migrant Labour Hostel
	Multi-family	Mixed	Informal dwelling/shack
	Multi-family	Mixed	Private residential house

	Multi-family	Mixed	Informal dwelling/shack
	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Informal	Informal dwelling/shack
	Multi-family	Mixed	Informal dwelling/shack
	Multi-family	Mixed	Migrant Labour Hostel
	Multi-family	Formal	Migrant Labour Hostel
	Multi-family	Formal	Migrant Labour Hostel

	Not Applicable	Formal	Informal dwelling/shack
	Multi-family	Formal	Migrant Labour Hostel
	Single	Mixed	Informal dwelling/shack
	Single	Formal	Private residential house
	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Multi-family	Formal	Private residential house
	Multi-family	Formal	Private residential house
	Multi-family	Formal	Private residential house
	Multi-family	Formal	Private residential house

	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Multi-family	Formal	Rowhouse
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house

	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Multi-family	Formal	Rowhouse
	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public

	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Multi-family	Formal	Government RDP
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse

	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse

	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse

Appendix B-2: Buildings captured in Manenberg

Photo	S, M, NR	Formality	Type
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Rowhouse
	Multi-family	Formal	Rowhouse
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Multi-family	Formal	Rowhouse/1- and 2-storey
	Multi-family	Formal	Rowhouse/1- and 2-storey

	Multi-family	Formal	Rowhouse/1- and 2-storey
	Multi-family	Formal	Rowhouse/1- and 2-storey
	Multi-family	Formal	Rowhouse/1- and 2-storey
	Multi-family	Formal	Rowhouse/1- and 2-storey
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"

	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	2-storey
	Multi-family	Formal	2-storey
	Single	Informal	Informal dwelling/shack
	Single	Informal	Informal dwelling/shack
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Not Applicable	Formal	Non residential/public

	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Maisonette
	Single	Formal	Maisonette
	Multi-family	Formal	2-storey
	Multi-family	Formal	2-storey

	Multi-family	Formal	2-storey
	Not Applicable	Formal	Non residential/public
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Government temporary housing

	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	Government temporary housing
	Multi-family	Formal	2-storey
	Multi-family	Formal	2-storey

	Multi-family	Formal	2-storey
	Multi-family	Formal	2-storey
	Multi-family	Formal	2-storey
	Multi-family	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Multi-family	Formal	Maisonette
	Multi-family	Formal	2-storey
	Single	Formal	Private residential house

	Multi-family	Formal	Maisonette
	Multi-family	Formal	Apartment
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Multi-family	Formal	Maisonette
	Multi-family	Formal	2-storey
	Not Applicable	Formal	Non residential/public
	Single	Formal	Private residential house
	Not Applicable	Formal	Non residential/public

	Multi-family	Formal	Maisonette
	Multi-family	Formal	Maisonette
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Maisonette
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Multi-family	Formal	Maisonette
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Maisonette

	Multi-family	Formal	Maisonette
	Not Applicable	Formal	Non residential/public
	Not Applicable	Formal	Non residential/public
	Multi-family	Formal	2-storey
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	2-storey
	Single	Formal	Private residential house
	Single	Formal	Private residential house

	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Single	Formal	Private residential house
	Multi-family	Formal	2-storey
	Multi-family	Formal	2-storey
	Multi-family	Formal	Maisonette
	Multi-family	Formal	Court/"korre"
	Multi-family	Formal	Court/"korre"

	Multi-family	Formal	Maisonette
	Multi-family	Formal	Maisonette